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TITLE: A Cooperative Communication System for the Advancement of Safe, Effective, and Efficient Patient Care

PRINCIPAL INVESTIGATOR: Christopher Nemeth, PhD

CONTRACTING ORGANIZATION: Applied Research Associates, Inc.
FAIRBORN, OH 45324

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Christopher Nemeth, PhD.; Shilo Anders, PhD.

E-Mail: cnemeth@ara.com

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14. ABSTRACT
The Cooperative Communication System (CCS) is intended to improve patient care by supporting Burn ICU clinical decision making through computer-based decision and communication support. This project is divided into three phases: foundation research, prototype development, and prototype assessment. In Phase 1, we collected and analyzed data on clinician patient cared and unit management, producing 39 requirements for the CCS. During Phase 2, we have developed user-oriented use cases and information design prototypes based on Phase 1 findings. We have developed a software prototype that translates the information design's organization and information into an interactive interface. Our subcontractor has also begun to develop approaches to machine learning that will survey patient data to detect patterns and trends that are clinically relevant. We are developing criteria to evaluate the programming prototype at the USAISR, which is scheduled for early December. The main challenge during this phase has been difficulty gaining access to patient data. We have been informed a development environment will be made available for us to use in October 2014. We have requested and obtained a no-cost extension through mid-December 2014, and are awaiting Year 3 funding.

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1. Introduction and Project Overview

The U.S. Department of Defense maintains one of the largest healthcare networks in the world, supporting in-patient and out-patient care not just for the active military, but their families, reserve forces, veterans, and even civilians local to various military treatment facilities (MTF). As such, each MTF experiences a wide variety of patients and clinical requirements.

Intensive Care Unit (ICU) patients present healthcare teams with unique challenges and complex combinations of life-threatening injuries and illnesses. Care for these patients is necessarily multidisciplinary. Care providers across professions must collaborate to make effective decisions, develop treatment plans, assess patient progress, and refine management over time. Management decisions, though, are only as good as the information available when they are made. For this reason, the Institute of Medicine recommended improving access to accurate, timely information, and making relevant information available at the point of patient care to improve patient safety. Despite advances in computer systems and knowledge resources, communication failures between resources and healthcare providers continue to cause the majority of misadventures in healthcare delivery. Critical information for decision making remains difficult to access and deliver, and is often missing at decisive moments.

Healthcare providers in an ICU environment amount to a joint cognitive system that can be studied, modeled, and assisted through scientific methods and information technology to improve decision making and, thus, improve patient care. The daily work of the clinician requires knowledge representations as part of this joint cognitive system to serve as a map for the ever-changing environment of work that must be successfully navigated.

As we envision it, the Cooperative Communication System (CCS) is part of a joint cognitive system that allows the healthcare team to remain connected to an individual patient and to each other across time and space as the team delivers patient care. As such, it can keep providers informed of a patient's status, of other healthcare providers' activity related to each patient, and of potential discrepancies among healthcare providers' broadly defined, patient driven goals, specifically defined objectives, and individually focused tasks. This type of networked system could also extend beyond the fixed walls of a hospital to incorporate pre-hospital, contingency operations, and theater evacuations. For example, when a soldier is injured, a networked communication system could immediately start relaying information to a Forward Surgical Team or Combat Support Hospital to keep the receiving healthcare team apprised of the patient's status so that they can adequately prepare. Handoff on arrival is then facilitated. The enhanced communication afforded by this system will decrease complications which will directly improve patient outcomes.

In addition to the improved communication among providers, this project explores the potential to provide relevant information to support clinician decision making. The potential exists for the use of artificial intelligence algorithms to display pertinent, prioritized information to a specific healthcare provider to support their current task. As more data becomes available to the AI system during patient care, the CCS will continuously (in real time) improve its availability and priority of the information displayed. This type of decision support should aid care providers from novice to experienced clinician by expanding support for decision making. Through decision support, patients might receive more accurate and timely diagnoses, more timely and appropriate testing, and best evidence-based care. The time lag from "bench-to-bedside" evidence-based interventions can be markedly reduced. Through better communication among the healthcare team and by dramatically enhancing the availability of salient information necessary to make decisions, we expect the CCS to reduce complications and costs and to improve overall patient outcomes.

The goals of this project include:

- PHASE 1: Describe patient progress through intensive care to create a shared mental model for clinicians of all specialties;
- PHASE 1: Provide a thorough account of the clinician cognitive work (i.e., work flow and decision requirements) for clinical work in the ICU, including accountability of all pertinent recorded and non-recorded data;
- PHASE 1: Present design requirements for the information, the underlying cognitive networking rules, and the display format of an IT-based cognitive aid for healthcare delivery (the Cooperative Communication System);
- PHASE 1: Derive quantitative evaluation criteria for comparative evaluation of clinical support tools;
- PHASE 2: Present a prototype CCS design for testing and implementation in the USAISR Burn ICU;
- PHASE 3: Develop a test bed based on the clinical environment for Test and Evaluation of the CCS and other clinical support tools.

Phase 1 tasks developed a valid understanding of the Burn ICU work domain, and individual and group cognitive work:

- *Task 1.1: Initial Observation of the Burn ICU.* Through observation and informal interviews, ARA will identify care activities, workload requirements, decisions in patient care, and the cognitive artifacts clinicians use and create a structured interview guide that will drive the remaining work of this phase.
- *Task 1.2*: *CTA Structured Interviews and Observation.* ARA will conduct CTA based on the observations from Task 1 and the interview guide. The structured interviews with clinicians will identify the processes, tools and cognitive artifacts, and data they use during their patient care activities.
- *Task 1.3*: *Integrated Data Analysis and Model Development*. ARA will analyze the data gathered in Tasks 1 and 2 and build valid representations of the cognitive work.
- *Task 1.4*: *Decision Model and Design Requirements*. ARA will develop specific decision requirements that are necessary for care management in the ICU.

Phase 2 tasks use Phase 1's research to develop design requirements for the IT-based cognitive aid, evaluation criteria, and a functional prototype of the CCS design:

- *Task 2.1*: *Scoping and Planning*. The ARA and the USAISR will translate the Phase 1 findings into detailed software requirements.

- *Task 2.2*: *Analysis*. The ARA and the USAISR will analyze software requirements and write preliminary designs focused on the user interfaces and main architectural features.
- *Task 2.3*: *Design Phase*. The ARA, the USAISR, and the SSCI will develop the software designs including specific coding and communication details.
- *Task 2.4*: *Implementation, Integration and Testing*. ARA. the USAISR, and SSCI will perform routine regression testing throughout the software coding effort. The culmination of these tasks is a user acceptance test of the application.

Should funding be made available for Year 3, the project team will perform a thorough evaluation of a series of prototype versions with clinicians at the USAISR.

- *Task 3.2: Evaluation Testing.* ARA use outcome-oriented evaluation to assess the prototype CCS concepts.

2. Accomplishments

For the past year, the ARA, the USAISR, and the SSCI project staff members have worked to refine Phase 1 results, including the design requirements, and to develop the CCS prototype.

During Phase 2 of the project, we completed data collection with one week-long site visit to the Burn ICU followed by intensive two-day analysis sessions. We performed this site visit to complete Task 1.1 and Task 1.2 and to validate the study results, the cognitive model assumptions, and to verify design requirements (Task 1.3 and Task 1.4). Analysis sessions were devoted to data review and assessment, and the development of both decision requirements and representations of individual and team cognitive work performed in the USAISR Burn ICU (Task 1.3 and Task 1.4). In addition to analysis sessions, the team conducted two design workshop sessions, where we translated findings into design requirements (Task 2.1) including detailed use cases. We translated initial design ideas that were developed during the design sessions into information design prototypes, then validated these with clinicians during a final site visit (Task 2.2). The modular prototype that ARA and our subcontractor SSCI are developing is based on results of all preceding tasks. We plan to test the first prototype with clinicians in December 2014 (Task 2.3).

a. Data Collection

The team performed all on-site observations and interviews, and removed all patient personal health information (PHI) and personally identifiable information (PII), in accordance with the IRB-prescribed procedures.

ARA researchers collected data at the USAISR during the week of November 18-22. The research team included three members from Cognitive Solutions Division, supported by a member of ARA's San Antonio Office. During the trip, the research team conducted 10 interviews with members of the USAISR Burn ICU clinical and support staff that lasted an average of 20 to 30 minutes. The visit gave the research team the opportunity to fill gaps that had been identified during data analysis sessions. Gaps included identifying key areas of information exchange between Burn ICU staff, such as patient trips to the OR, shift changes, and patient transitions into and out of the unit. Each made a more focused observation possible to better understand the exchange. The research team also collected more data from residents and medical students on their roles and needs. ARA researchers verified findings from the analysis and data synthesis, as well as beginning system requirements, with key Burn ICU staff members.

ARA team members also circulated through the BICU to observe clinical activities and occasionally ask informal questions of those who had consented to participate in the study. To verify face validity, the research team also reviewed requirements tables from the November data analysis meetings with a range of clinical roles (e.g., RN, LVN, Occupational and Physical Therapists, and Physical Therapist Assistant, Respiratory Therapist, and Intensivist). A report for this visit is in Appendix A.

The on-site research nurse has continued to assist the research team with data collection. She helped satisfy IRB human-subject research requirements and, as of November 22, 2013, had obtained the consent of 151 Burn ICU staff members. She has established a rapport with Burn ICU staff and key personnel in the ISR. She has also answered numerous questions the research team has had about the Burn ICU, including Burn ICU layout, staffing requirements, staff communication, workflow, staff duties, and standard procedures.

b. Data Analysis

During the reporting period, the ARA team also conducted a series of intensive 1-2-day data analysis sessions on August 27-29, November 5-7, and December 16. Elaborating on the first year analyses, ARA researchers initially met to walk through initial themes to be further explored in the data. Data analysis meetings developed both initial descriptions of barriers the staff encounter and cognitive work they perform. Both are themes that appear across the majority of data the team has collected.

After the two-day session in August, a few of the team members met several times to further refine and define the themes that would be used to categorize the data. Upon agreement researchers then analyzed all of the interview and observation notes and categorized the data according to the agreed-upon cognitive themes and barriers that Burn ICU personnel experience. The notes included in each of these categories were then individually reviewed and synthesized for further themes in the data.

The team sorted summary statements according to the different themes in order to describe barriers, information requirements, and technology requirements. These were the beginning of the design requirements that were subsequently confirmed and expanded upon by Burn ICU personnel. These findings were developed into the Data Requirements Table is included in Appendix B. We refined the diagram (see Appendix C) that shows the information sources available to Burn ICU personnel, including who has access to the source, and what type of source it is (e.g., paper, electronic, combined paper/electronic, and communications). We also expanded the working relationships diagram to better define essential roles to include in the interface information views.

During the November data analysis session, the research team created a plan for the November data collection visit by identifying gaps that needed to be filled. The team also planned to verify findings from the analysis and the initial system requirements with key Burn ICU personnel.

The December analysis session was used to refine the design requirements following the November data collection visit. This resulted in the final design requirements as well as a complete description of barriers to patient care.

The team delivered the final report for Phase 1 in February 2014.

c. Evaluation Measures

Building on the design requirements, the team developed measures to assess CCS interface usability, how well the system meets the design requirements, how well the system supports cognitive work. The research team has assembled an initial set of metrics (see Appendix D) that will be used to evaluate CCS prototype usability. Subsequent measures now in development will be used to assess system requirements, cognitive work support, and clinical outcomes. Evaluation planned for Year 3 will seek to learn how it might affect specific clinical outcomes. We will continue to refine these measures while we develop the CCS prototype.

d. Use Cases

The team developed detailed use cases (see Appendix E) to illustrate how the design requirements supported the Burn ICU workflow. The use cases then served as the basis for machine learning use cases that subcontractor SSCI developed. ARA worked with the ISR and subcontractor SSCI, to develop a set of functional requirements and use cases (Appendix E) to apply machine learning capabilities within CCS. We identified three functional requirements for machine learning to meet: 1) Identification of clinician records for similar patients, 2) Prediction of future patient record state, and 3) Identification of significant patient and clinician records.

e. Information Design Prototypes

The ARA research team, ARA development team (Josh Blomberg), and SSCI (Rob Smith) met for a two-day data analysis and design session on December 16-18, 2013 in ARA’s Fairborn, OH office. The USAISR development team and Co-PI, Dr. Pamplin, participated by phone and FaceTime. During this session, the team refined and revised the design requirements based on feedback that was collected during the USAISR visit. The second day was dedicated to a design workshop session in which the group brainstormed design ideas that would facilitate timely, effective, and efficient patient care. During the session, team members jotted down ideas and shared using Post-It notes. The group then divided into smaller teams that designed rough representations of interfaces, then presented them to the larger group. The session provided the interface designer with beginning interface concepts to further develop and refine. The research team also updated and refined the use cases that the software development team would need.

The ARA team also held a similar design session at the USAISR on February 7, 2014 to capture clinician insights. Two members of the ARA research team conducted a design workshop including a discussion of the use cases followed by brainstorming activities and design workshops. We asked session participants to answer questions such as “What could a patient view look like?” To respond to the questions, the group divided into smaller teams according to clinical roles. Developers divided themselves among the different teams. Each created rough sketches of a display that made sense to them, then explained their concept to the larger group and discussed their reasoning with all participants.

The two design sessions (researchers and developers at ARA in Fairborn and the clinicians at the USAISR) generated nearly the same amount of brainstorming data and paper prototypes. This illustrates the power of the team’s methodology and its ability to capture and make sense of complicated and complex domains. Based on these sessions, the ARA team then developed several versions of the interface design, resulting in an information design prototype based on Year 1 findings and requirements.

Three members of the ARA research team, supported by one San Antonio office staff member, visited the USAISR in San Antonio March 23-28, 2014 for a design review and validation of the candidate displays by those who would use them. The research team identified gaps in the interface content and identified improvements that could be completed before programming began. The team also verified the key systems requirements with selected members of the Burn ICU staff. Using this information the display concepts were further refined to create the information design prototypes that are included in Appendix F.

f. Software Prototype

Josh Blomberg, of ARA, and Jeff Morrison, of SSCI, met with the Task Area Manager, Jose Salinas, at the USAISR on 10 October to plan CCS software development. The discussion included USAISR software development requirements (including SOPs), and requirements for Information Assurance (IA) and medical device determination. Their discussion addressed an issue that has posed a major hurdle for the project: access to relevant medical databases during development. To gain access to actual patient data we would have to create an isolated development environment at the USAISR that is not connected to either the medical record or to the greater military network. Historical views of in-patient data could then be placed into this isolated network making it possible for the CCS system to be developed and tested using actual, although limited to only Essentris in-patient electronic health record data.

Over the past year, the ARA team and members of the USAISR staff have spent significant time and effort to gain access to relevant medical databases by pursuing both internal and external options. Among those initiatives, we found Phillips eICU patient data closest to CCS needs. After entering into a non-disclosure agreement with Phillips, Josh Blomberg of ARA obtained and loaded the test Phillips database, then analyzed the data set and determined that it would easily map to the relational database used in CCS.

On September 5th, USAISR Information Management Division (IMD) staff gave USAISR software engineers access to the isolated development environment. As we complete this report, we are waiting for necessary electronic medical record data to be loaded into this environment and begin to add necessary software programs to it.

As we explored these data access options, we continued to advance the prototype development process, as described below.

i. Architecture

ARA developed a system architecture that describes how to integrate the CCS user interface, machine learning, electronic medical record databases, and data warehouse components. We are pursuing a modular system architecture connected to notional medical databases. During the past year, we also discussed software architectures that are approved for use within the ISR environment, and determined that ARA's proposed web-based architecture satisfies initial system requirements and has a defined pathway to gain approval for use on DHA networks.

ARA has an initial environment for software development and integration, and established a repository for version control. Accounts have been created for ARA and SSCI personnel. ARA began prototyping a web-based user interface for CCS based upon the information design prototypes. ARA also began to create the architecture for a CCS web site and for integration of SSCI's component technologies. The architecture is based on ASP.NET web services and uses a Microsoft SQL Server database.

SSCI has also established a local repository of their software components and libraries that are intended to be used in CCS. These include the *PaRSA*, *POINT*, and *CrossCat* programs. *CrossCat* was developed as a part of DARPA's XDATA program to find relationship between columns of database content, and the MedMAPP system, developed for the NIH as a way to track medically-relevant trends in social media.

ii. User Interface

The CCS user interface will maintain a real-time view of the electronic health record and incorporate results from machine learning as they are made available via a relational database. To that end, ARA developed a customizable widget-based web framework for use in CCS. Users will be presented with a default CCS user interface view that can be customized. Our approach allows users to configure which data elements appear on their display. Developers will be able to note customization choices that users make.

Development and research teams reviewed and improved versions of the software prototype and reviewed it with selected USAISR prospective users for their feedback. The development team was given access to the records of two deceased patients in August, as part of a IRB sanctioned non-human subjects research protocol. The team is now connecting components of the interface to these patient data. Future versions of the CCS prototype may also mine data on how clinicians customize the interface to detect possible relationships between display customizations and patient outcomes.

iii. Machine Learning

SSCI is responsible for the development of the machine learning features of CCS. These will periodically poll the electronic health records to populate a data warehouse. Their analytic software will review those data to extract patterns based on user queries. The results will be transferred to the CCS database and used to invite clinician attention to patterns that might otherwise remain unnoticed.

During this year, SSCI developed a draft application programming interface (API) for the data analytics module that will be delivered during development and testing of the final CCS prototype. In June, SSCI demonstrated their data analytics engine based on SSCI's implementation of a scalable Bayesian inference technology known as *CrossCat*. The engine can be hooked to generic databases, as well as during notional testing to show how the engine can handle mock medical data. The engine runs asynchronously in the background using existing patient data. At the same time, it can also deliver the specific items noted below in real time, based on the engine's current best model learned from the existing data.

Our inability to obtain access to patient data has so far prevented SSCI from developing a machine learning capability that is customized to USAISR data. Instead, SSCI has developed a generic engine that can be quickly adapted to: a) whatever data sets eventually emerge, b) a wide variety of required prediction and analysis tasks, as the requirements in the rest of the project team clarify, and c) the scale of the datasets with which we may have to handle. The background engine's built-in ability to be distributed across multiple computers should enable CCS to manage large datasets.

Only very limited Essentris data has been made available for development at the time of this report. To mitigate this challenge, SSCI has developed a technique to expand the volume of available data if Essentris data access remains limited. This technique is to create synthetic seeded patient condition data, by using the *CrossCat* search engine. By inferring the statistics of relevant data fields using relevant samples of data, we can use the engine to generate synthetic data with known and relevant statistical properties. After this, confirmation of the system's correct operation later in referencing real patient data is straightforward.

As the CCS project proceeds, we expect adaptation of SSCI's machine learning approach should be a matter of supervised learning: asking the search engine the right questions, and providing it with the right data. These adaptations will not require significant development within the engine itself. After the initial check-in and demonstration of the prototype, we expect to spend the remainder of this project year completing adaptations and refinements according to the development milestones (Appendix G). While some tasks have been completed, others have been re-planned based on coping with data availability issues.

3. Deliverables Status

The deliverables to date include:

1. Approved Human Subject Protocol: Final approval completed 27 February 2013, Amended protocol approved April 30, 2013
2. Visit Reports (x4):
    a. First site visit March 4-8, 2013
    b. Second site visit May 20-24, 2013
    c. Third site visit July 22-25, 2013
    d. Fourth site visit November 18-22, 2013
3. Initial Software User Interfaces: January 2014
4. Burn ICU Cognitive Model: February 2014
5. Phase 1 Final Report: February 2014
6. Finalized User Interfaces: April 2014
7. Initial Burn ICU Metrics: September 2014

Pending deliverables include:

8. Controlled test environment: Started, delivery October 2014
9. First iteration of working Prototype: Started, delivery December 2014
10. Interim user evaluation of prototype: expected December 2014
11. Final Report Phase 2: expected February 2015

Provision and delivery will depend on the no-cost extension and Year 3 funding:

12. Second iteration of prototype: expected March 2015
13. Second interim user evaluation of prototype: expected April 2015
14. Third iteration of prototype: expected June 2015
15. Third iteration of prototype: expected July 2015
16. Finalized CCS program: expected August 2015

The following activities are planned for September-December 2014:

a. Complete an initial CCS prototype (Task 2.4)
b. Finalize assessment metrics and conduct evaluation testing (Task 3.2)
c. Develop and verify initial notions of scenarios (Task 3.1 & Task 3.3)
d. Conduct usability assessment of prototype (Task 3.4)

4. Administrative

Applied Research Associates, Inc. (ARA) has been under Contract W81XWH-12-C-0126 to the U.S. Army Medical Research & Material Command's (USAMRMC) Telemedicine & Advanced Technology Research Center (TATRC) for two years. CCS prototype progress has been delayed due to unforeseen challenges in obtaining access to patient data and the databases required for Phase 2 development work. Based on this delay, we requested and obtained a no-cost extension to allow for the prototype to be developed and connected to a database with actual de-identified patient data.

5. Equipment and Supplies

During the year, the team acquired a software development package with standardized graphics to aid the computer programing team.

6. Reportable Outcomes

During the reporting period, the research team has produced the following professional publications, and presentations that are included in Appendices H through L.

Book Chapter

Nemeth, C., Anders, S., Brown, J., Grome, A., Crandall, B., & Pamplin, J. (in press). Support for ICU clinician cognitive work through CSE. In A. Bisantz, C. Burns & T. Fairbanks (Eds.), *Cognitive engineering applications in health care*. Boca Raton, FL: Taylor and Francis/CRC Press. *(editor proof provided)*

Proceedings

Nemeth, C., Anders, S., Grome, A., Crandall, B., Dominguez, C., Pamplin, J., Mann-Salinas, E. & Serio-Melvin, M. (2014, October). *Support for ICU resilience: Using Cognitive Systems Engineering to build adaptive capacity.* Proceedings of the Systems Man and Cybernetics Society 2014 International Symposium, San Diego. *(oral presentation)*

Presentations

Nemeth, C., Anders, S., Brown, J., Crandall, B., Grome, A., Chung, K., Mann-Salinas, E., & Pamplin, J. (2014, January). *Discovery of Burn ICU critical care complexities and the implications for Health IT Design*. Poster presented at the Society of Critical Care Medicine, San Francisco. *(poster presentation)*

Pamplin, J., Anders, S., Brown, J., Crandall, B., Grome, A., Chung, K., Mann-Salinas, E. & Nemeth, C. (2014, January). *Use of Cognitive Systems Engineering to reveal burn ICU decision-making and information sources to aid health information technology design in the Burn ICU*. Symposium conducted at the Society of Critical Care Medicine, San Francisco. *(oral presentation)*

Nemeth, C., & Pamplin, J. (2014, August). *Developing a cognitive and communications tool for Burn ICU clinicians*. Symposium conducted at the Military Health System Research Symposium, Ft. Lauderdale, FL. *(oral presentation)*

7. Conclusions

Cognitive Systems Engineering (CSE) group's study of work and information flow through this DOD critical care facility in Year 1 produced a descriptive model of patient progress through the ICU, including clinician decision requirements. The resulting description of the work domain, information sources, and clinician work practice yielded

39 requirements for the CCS prototype that are now being developed in Phase 2, and criteria that will be used to evaluate the prototype in Phase 3.

During Phase 2, we have developed user-oriented use cases and information design prototypes based on Phase 1 findings. We have developed a programming prototype that translates the information design's organization and information into an interactive interface. Our subcontractor has also begun to develop approaches to machine learning that will survey patient data to detect patterns and trends that are clinically relevant. We are developing criteria to evaluate the programming prototype at the USAISR, which is scheduled for early December.

The main challenge during this phase has been difficulty gaining access to patient data. We have been informed a development environment will be available for us to use in October 2014. We have requested and obtained a no-cost extension through mid-December 2014, and are still awaiting Year 3 funding.

As the study continues, the research team plans to:

- Finish prototype development, including the ability to mine data for relevant information.
- Test and validate the prototype in concert with other IT solutions currently in use. Assessment criteria based Year 1 research will be used to evaluate prototypes.
- Seek avenues to test and validate in an actual clinical setting.

The system it produces is expected to improve communication, information flow, and workflow among and across clinical providers and support staff.

8. References

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Nemeth, C., Anders, A., Dominguez, C., Crandall, B, & Grome, A. (2014, February). A cooperative communication system for the advancement of safe, effective, and efficient patient care. Phase One Final Report. Contract W81XWH-12-C-0126. U.S. Army Medical Research and Material Command. Ft. Detrick, MD.

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9. Appendices

Appendix A. AISR Trip Report – November 2013

23 November 2013

From: Christopher Nemeth, PhD
To: Betty Levine, TATRC
Cc: LtCol Elizabeth Mann-Salinas, US Army Institute for Surgical Research

Subj: Trip Report: AISR Data Collection 17-22 Nov 2013

1. Executive Summary. Applied Research Associates, Inc. (ARA) is under Contract W81XWH-12-C-0126 to the U.S. Army Medical Research & Material Command's (USAMRMC) Telemedicine & Advanced Technology Research Center (TATRC). The Cooperative Communication System is intended to be part of a joint cognitive system that allows the healthcare team to remain connected to an individual patient and to each other across time and space as the team delivers patient care. In addition to the improved communication between providers, this project explores the potential to provide relevant information to support clinician decision making. Data collection visits during Year One provides the descriptive model and decision requirements for Year Two prototype development.

2. Staff. Three members of the Applied Research Associates research team made this trip to San Antonio: Shilo Anders, PhD, Anna Grome, and Christopher Nemeth, PhD. Dianne Hancock from the ARA San Antonio office supported the visit.

3. Activities. All information was collected in accordance with IRB-prescribed procedures to remove patient personal health information.

a. Interview. To learn answers to questions developed in November data analysis sessions, conducted 10 interviews lasting an average of 20 to 30 minutes each with members of the AISR Burn ICU clinical staff in the following roles:

Intern
Burn OR Chief Nurse
Anesthesiologist
Bedside Nurse (3)
Respiratory Therapist
BICU Chief Nurse
Charge Nurse (2)

b. Observation. Team members circulated through the BICU to observe clinical activities, and ask occasional informal questions of those who had consented to participate in the study.

c. Review. To verify face validity, Ms. Grome, Dr. Nemeth, and Dr. Anders reviewed requirements tables from the November data analysis meetings with a range of roles: Bedside Nurse (RN, LVN), Occupational and Physical Therapist and Physical Therapist Assistant, Respiratory Therapist, and Intensivist.

d. Task Area Manager Meetings.

- Dr. Nemeth and Ms. Grome met on November 17 with LtCol Pamplin to discuss Phase 1.
- Dr. Nemeth and Dr Anders met on November 22 with Task Area Manager Dr. Salinas, LtCol Pamplin, and Ms. Mario-Selvin to discuss Phase 2.

4. Results. The research team developed a number of work in-progress items to begin concept development, support data analysis, and prepare for the next data collection visit.

a. Interview notes. In-depth notes accounting for data that were collected according to the November data analysis session notes

b. Observation notes. Notes team members made during observations and brief discussions with members of the BICU clinical staff.

c. Annotated requirements tables.

d. Diagrams. Scale drawing of the BICU and OR spaces floor plan.

e. Annotated draft of book chapter accepted for upcoming CRC Press text *The Handbook of Cognitive Engineering in Healthcare.*

5. Further work. Next steps for the project will be to:

a. Review results from this data collection visit.
b. Translate field drawing into finished illustration.
c. Revise requirements tables

6. For further information, contact Dr. Nemeth at 937-825-0707, or cnemeth@ara.com.

Appendix B. Data Requirements Table

Based on the synthesis and integration of findings, the team developed an initial set of system requirements for CCS using the following questions:

- What is the barrier or challenge the clinical team faces?
- What does the clinical team need/require to overcome that challenge?
- What system or display features could help address that challenge?
- What is the anticipated impact of meeting that requirement on team coordination, efficiency, and patient care?

This Appendix contains the full set of initial requirements, the problems they are intended to address, the system features suggested by requirements, and initial ideas about how system features might affect patient care, efficiency and length of stay.

Problem/Barrier	Needs/Requirements	System Feature Concepts	Anticipated Impacts
No effective means to synchronize and adapt different aspects of patient care over the course of a shift (e.g., among RN, OT/PT, wound care) Lack of awareness around activities/ events that are tightly coupled No efficient communication of patient status	▪ Need to determine optimal timing and sequence of activities ▪ Need awareness of planned/scheduled patient care activities (e.g., wound care, rehab, line changes, etc.) ▪ Means to share the plan ▪ Means to adapt the plan in real time and share changes across the team. ▪ Bedside Nurse needs to shift the goals and priorities ▪ Means to know how changes in orders affect/ change planned activities ▪ Means to know what	▪ Visualization of patient schedule for shift (patient x time), shareable across team ▪ Ability to sequence or overlap patient care activities ▪ Configurable patient groupings ▪ Prepackaged text to indicate changes to schedule (e.g., there's a ½-hour delay in PT) ▪ Sequence, time of planned activities ▪ Provide reason for delay, and remedy (using pre-packaged text) ▪ Overview through time, for unit management ▪ Visually connect interdependent events	▪ Patients get needed care with fewer delays ▪ Efficient use of staff time ▪ Reduces unmet treatment plans and intentions ▪ Supports re-planning – helps staff identify windows of opportunity

Problem/Barrier	Needs/Requirements	System Feature Concepts	Anticipated Impacts
change across disciplines	planned events are and who needs to be there ▪ Practitioners need to understand what's going on with their group of patients across the shift (whatever their group happens to be)	▪ Prompt/notify appropriate person when change impacts their activity (e.g., when wound care impacts PT/OT and RT)	
Updated information is available but not readily accessible or visible to clinicians (e.g., cultures)	▪ Clinicians need to be aware that updated information is available, particularly re: lab cultures	▪ System provides news feed from lab about cultures. ▪ Red/amber/green about status of labs (received or not; in progress; completed)	▪ Fewer care delays ▪ More efficient tracking and follow up ▪ Better use of staff time ▪ Less reliance on verbal exchanges
Orders late, missing, or overtaken/replaced by other orders Reliance on verbal orders and no standardized way to share orders	▪ Need efficient, accurate way to specify meds, procedures ▪ Physicians need access to orders from Charge Nurse's checklist ▪ Physicians need prompts to enter orders ▪ Need indicator of status of order entry (has it been placed or not?) ▪ Need indicator of status of order (in process, completed) ▪ Physicians need to be aware when entering order that it's the same as or different from previously	▪ Order pick list and window per patient to support real-time order entry during rounds ▪ Order status (have orders been received? Completed?) ▪ Notify others if needed (e.g., infections control) ▪ Provide prompt for delayed order entry (based on programmable timing tripwire) ▪ Display the information required to make decisions about an order available with the order (the relevant parameters) ▪ Provide molar/aggregated view of delays for a given patient ▪ System will track (and possibly highlight) when an order has	▪ Fewer care delays ▪ More efficient order entry and tracking ▪ Better use of staff time – reduced need for repeated follow-ups ▪ Reduced reliance verbal orders

Problem/Barrier	Needs/Requirements	System Feature Concepts	Anticipated Impacts
	entered orders ▪ Changes to orders need to be disseminated to wider team so that team has common ground. Changes in orders need to be apparent to whole team	been changed. ▪ System will provide timestamp for orders	
Documentation requires significant time from key members of the clinical team (RNs, Residents, RTs, etc.) and is often redundant	▪ Information Management tools and processes built around efficient use of staff time and effort ▪ Minimize staff time required to capture information by reducing redundant information gathering and entry ▪ Minimize staff time spent as the 'system integrators' who move data from one system to another ▪ Need 'user-friendly' interfaces/systems	▪ System built on a relational database that has all the information relevant to a given patient, so that there is true interoperability: ability of separate systems to cross-populate data, in real time ▪ System supports capturing and displaying time-based, patient-based, unit-based data ▪ Interfaces support simple data entry and pulling information (faster, more efficient documentation; errors/ disconnects more easily spotted) ▪ System's ability to recognize 'repetition' when new documentation is introduced (e.g., 'we already capture that data over here') ▪ System features that scan new documentation requirements for novel information/redundancies (don't just add more)	▪ Decreased time spent entering, moving, repeating, re-entering, data ▪ More time with patients; increased ability to attend to patient issues and needs ▪ Decrease cognitive workload ▪ Decrease in potential data entry errors (repeated entry of same data increases chance for error)

Problem/Barrier	Needs/Requirements	System Feature Concepts	Anticipated Impacts
Lags in information updates means information in system is sometimes stale/inaccurate	▪ Means to indicate if patient is highly unstable (because information for unstable patients can become inaccurate in short timeframe) ▪ Means to know whether information in system is up-to-date (e.g., is this an accurate reflection of the patient's status right now?) ▪ Means to know whether orders are in process but results not entered into system yet (e.g., cultures, lab results) ▪ Means to know recency of information updates ▪ Means to capture and disseminate changes to orders that occur verbally within sub-teams	▪ Information should be time stamped(Q: which information in particular?) ▪ System should highlight recent results (e.g., lab results, cultures). And also highlight orders that are in process ▪ System should highlight/provide alert when orders are changed ▪ System should highlight/alert staff to contraindications (e.g., patient positioning, nutrition)	▪ Optimized patient care ▪ Better use of staff time – reduced need for repeated follow-ups ▪ Reduced reliance verbal orders ▪ Reduced potential for error
Trends are important information, but can't get them from Essentris or other IT. No ability to keep track of patient status over time > 24 hours.	▪ Clinicians need trend information ▪ Need view of patient that is more than just this shift. Both macro level view of indicators and over longer time spans	▪ System should display trend information for key parameters (to be identified by clinical staff) ▪ System should provide trend information over different time slices ▪ Provide access to views of patient beyond current 12 or 24 hours	▪ Optimized patient care ▪ Increased ability to spot changes in patient status, intervene quicker

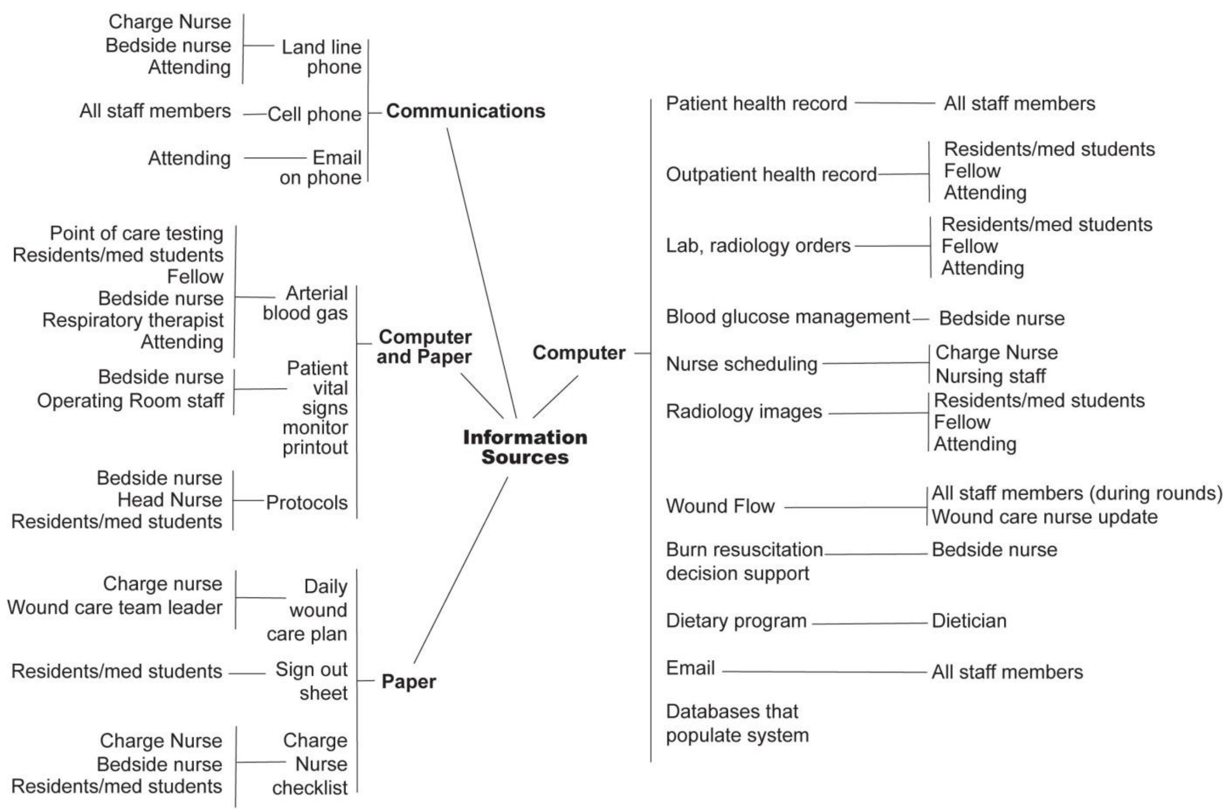
Problem/Barrier	Needs/Requirements	System Feature Concepts	Anticipated Impacts
What clinical staff are currently on the unit?	▪ Need to know who is available, and where to find them ▪ Need access to nurse assignments by shift, by patient ▪ Means to access assistance, guidance, decision makers ▪ Need to know which specialty is assigned to each patient (e.g., RT) and patient acuity	▪ Names of who is working on unit that day, with patient assignments by room ▪ Call/staff assignment roster ▪ Shareable across disciplines ▪ Map view of floor and display showing location of staff. ▪ Text paging/pre-populated messages ▪ ID with RFI tag	▪ Allows staff to readily know who is available so they do not spend time away from patient trying to locate staff ▪ More efficient communication ▪ Mitigates care delays ▪ Can get help when it is needed
Is patient ready for upcoming surgical procedure	▪ Need means to know whether patient is prepared for procedure (have they gotten blood products, antibiotics, consent, pregnancy test)	▪ Provide roster of needed items (e.g., blood, antibiotics) and indication of whether those items have been satisfied	▪ Prevent delay in procedures
OR RN does not know enough about upcoming procedure to prepare surgical suite properly Bedside RN does not know enough about surgery as it is being performed to prepare properly for patient's return	▪ OR nurse needs procedure specific description (need to know more about specific information needs) ▪ Bedside Nurse needs means to know what to expect re patient needs following procedure (e.g., what was worked on, how much blood given or lost, sedation?)	▪ Provide information about intended procedure ▪ Provide information about surgery in process and patient status	▪ Nursing staff better prepared to care for specific patient needs at earliest opportunity

Problem/Barrier	**Needs/Requirements**	**System Feature Concepts**	**Anticipated Impacts**
Rounding Checklist not readily available/access-ible to all members of clinical team Impact of dropped tasks, gaps, and lapses not known or tracked Checklist management is unclear (responsibility for making sure items are completed is unclear).	▪ Means to construct checklist in real time (during Rounds) or immediately after ▪ Means to post checklist so all staff have ready/easy access ▪ Means for staff to 'check off' completed items, makes notes re: hold ups, changes/revisions ▪ Means for incomplete items to 'roll over' to populate next day's check list and to be reviewed at next-day Rounds	▪ Checklist needs to interact with order and other clinical systems ▪ Unit level view that is easy to access and track ▪ "Roll up" function: ability to look across patients/shifts/types of activities to examine when there are particular activities consistently missed/delayed; or care for a particular patient consistently delayed ▪ System supports task tripwires (e.g., timing). Ability to recognize disconnects between orders and implementation (e.g., order entered, but not reviewed) ▪ Provides alerting function when tripwire is crossed ▪ Tripwires are definable by the staff	▪ Fewer care delays ▪ More efficient order entry and tracking ▪ Better use of staff time ▪ Reflect on/improve on checklist performance ▪ Potential unintended consequence: alarm/alert fatigue
Reliance on clinician to mentally integrate data	▪ Clinicians need a holistic/macro-view of the patient's trajectory (e.g., are they getting better or getting worse over last 24 hrs.?)	▪ Provide trend data and key indicators (e.g., for each of the main bodily systems) ▪ Trends on vitals, wound healing, medication dosing, infections	▪ Clinician better able to focus on problem detection, anticipate need for changes in treatment plans, optimize decision making around patient care

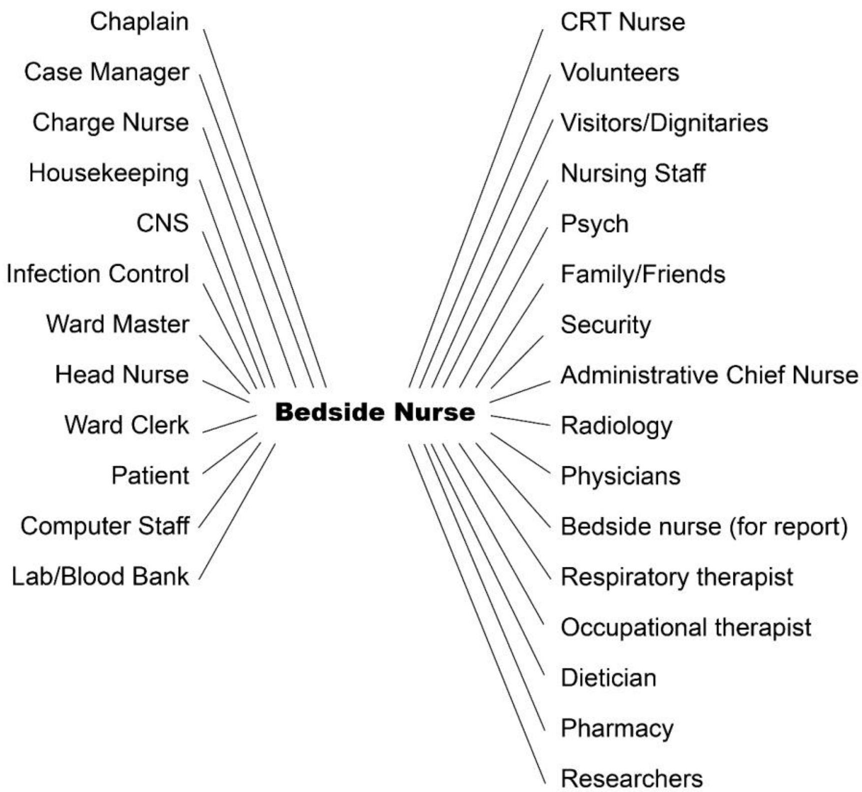
Appendix C. Burn ICU Representations

The research team developed diagrams to illustrate findings from Phases 1 and 2, including information sources Burn ICU clinicians use, working relationships they maintain.

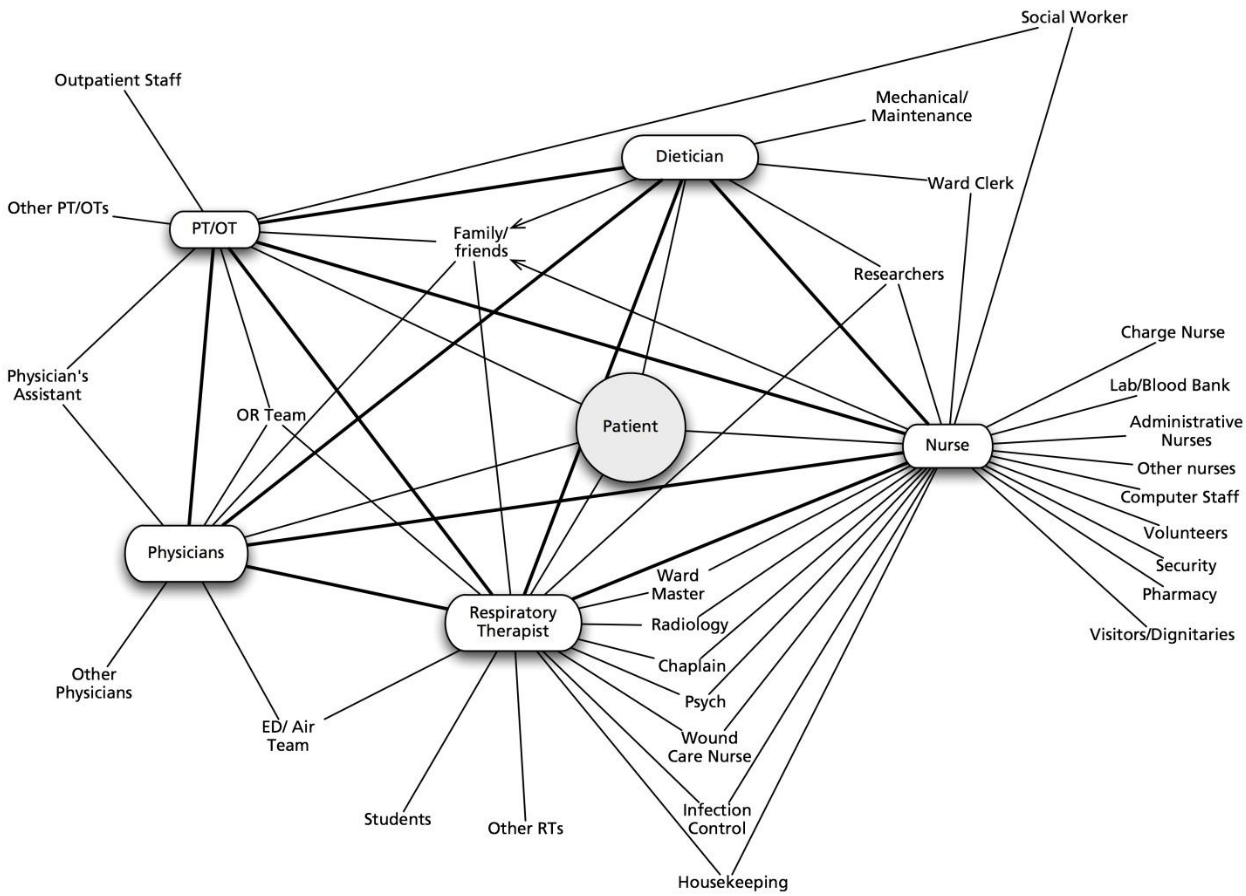
Information Sources. During our interviews and observations, we sought to find out what information sources Burn ICU staff members use. The following diagram shows each source, according to who uses it and the type of source. Our data showed incompatibility among these sources is one of the significant barriers that the clinicians face. Success of the CCS will need to integrate this assortment of sources into a useful whole.



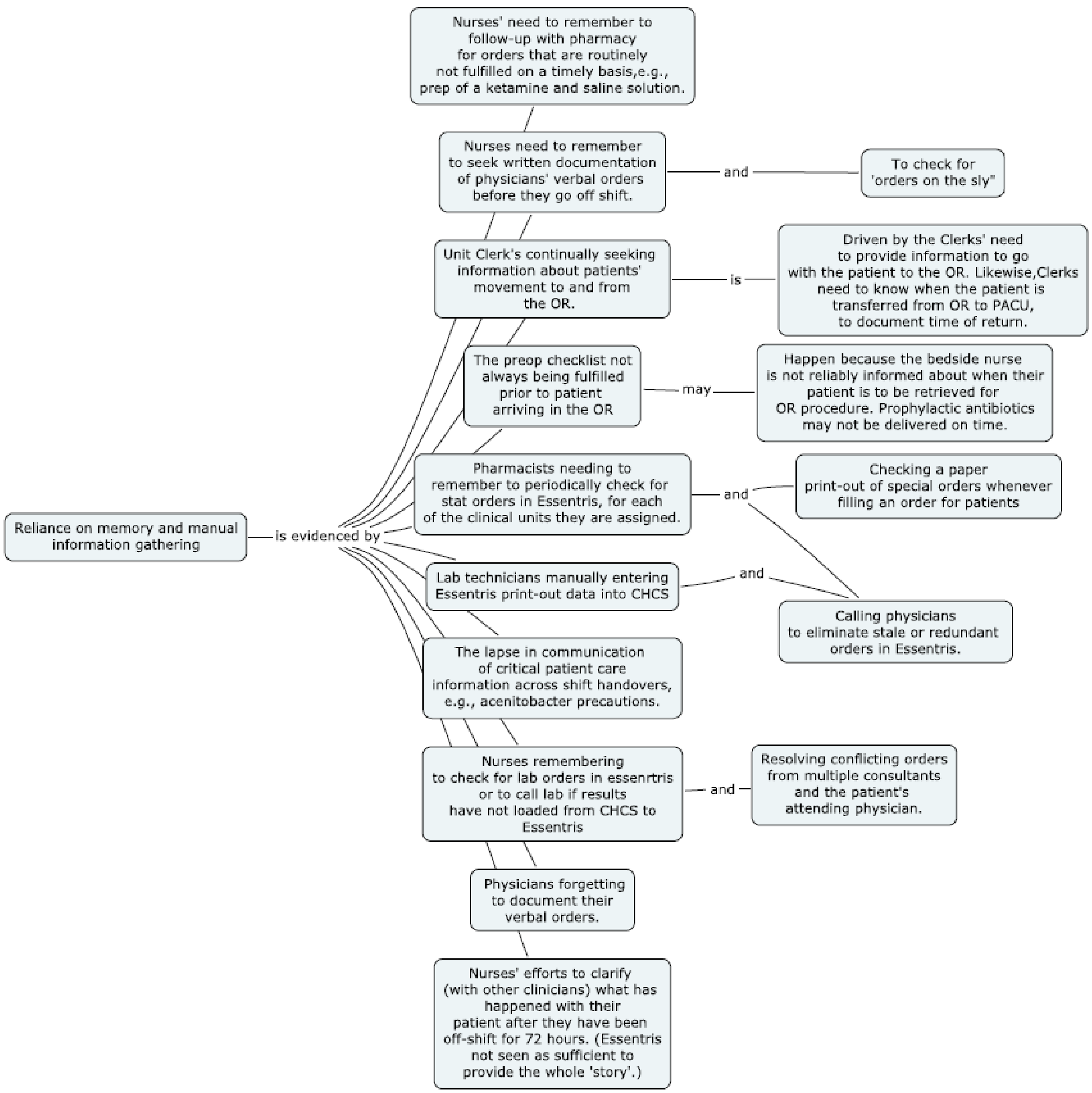
Bedside Nurse Communication. During Phase 1, the research team gathered information about who individuals communicated with while working on the unit. Initial focus of this data collection effort was on the Bedside Nurses, as they are closest to the patient. The following figure illustrates the 31 relationships the Bedside Nurse needs to manage.



Working Relationships. During Phase 2, we expanded the Bedside Nurse working relationships diagram to define the essential patient care team. This enabled the research team to identify the role-specific views and communication links that are most important to include in the first version of the CCS interface. We posed the question "Who do you communicate with to do your work?" to 8 nurses, 5 respiratory therapists, 2 PT/OTs, 1 Dietician and 1 Physician. Results from that brief survey yielded the following diagram. The rectangles represent the roles. Thicker lines show that the communication was mentioned by both parties.



Memory Reliance. The following concept map diagram illustrates how the ARA research team analyzed Burn ICU clinician reliance on memory to accomplish a task, and the implications it has for unit performance. The CCS is intended to spare clinicians from this reliance on memory.



Appendix D. Evaluation Measures

“Metrics” can be defined as measurable behaviors, work processes, technology features, clinical outcomes, and aspects of individual and team performance. Each reflects the problems, needs, and requirements that we identified during Phase 1 Cognitive Task Analysis (CTA).

The research team is developing an initial set of metrics to guide the evaluation of the CCS during its development in order to provide evidence of the how well CCS addresses those problems, needs and requirements.

“Methods” refers to the ways that metrics can be assessed. We are considering a range of methods that might be used to conduct evaluations. They include observations, surveys, interviews, extraction of data from existing sources, and time/distance measures.

Candidate metrics and measures for assessing CCS utility and usability follow:

Technology Metrics and Measures
Cognitive Performance Indicators (Wiggins & Cox, 2010): Methods might include expert review, interviews, surveys/questionnaires Metrics include: ▪ Cue Prominence: Systems should allow users to rapidly locate key cues from the information presented. ▪ Direct Comprehension: Systems should allow users to directly view key cues rather than requiring users to manually calculate information to comprehend these cues. ▪ Fine Distinctions: Systems should allow users to investigate or at least access unfiltered data. ▪ Enabling Anticipation: Systems should provide information that allows users to anticipate the future states and functioning of systems. ▪ Transparency: Systems should provide access to the data that it uses and show how it arrives at processed data. ▪ Historic Information: Systems should capture and display historic information to help users more quickly interpret situations and diagnose problems. ▪ Adjustable Settings: Systems should allow users to refine and adjust settings as they learn more about a situation. ▪ Situation Assessment: Systems should help users form their own assessment of a situation rather than provide decisions and recommendations.

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SUS (System usability Scale; Brooke, 1998): employs a questionnaire methodology, using a 5-point Likert scale. Metrics include: ▪ I think that I would like to use this system frequently. ▪ I found the system unnecessarily complex. ▪ I thought the system was easy to use. ▪ I think that I would need the support of a technical person to be able to use this system. ▪ I found the various functions in this system were well integrated. ▪ I thought there was too much inconsistency in this system. ▪ I would imagine that most people would learn to use this system very quickly. ▪ I found the system very cumbersome to use. ▪ I felt very confident using the system. ▪ I needed to learn a lot of things before I could get going with this system.

Error Analysis: most useful in the context of a scenario, methods might include observation, video recording analysis, think aloud protocols.

Metrics include:

- Use errors: missteps in the interface when trying to complete a task
- System errors: page doesn't display
- Error recognition: does the user realize they made a mistake?
- Error recovery
- Deviation from optimal path[1]

Nielsen's Heuristics (Nielsen, 1994): Likely methods include expert review, cognitive walkthrough

Metrics include:

- Visibility of system status: System should always keep users informed about what is going on, through appropriate feedback within reasonable time.
- Match between system and real world: System should speak the users' language, with words, phrases and concepts familiar to the user, rather that system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
- User control and freedom: Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
- Consistency and standards: Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
- Error prevention: Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
- Recognition rather than recall: Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
- Flexibility and efficiency of use: Accelerators – unseen by the novice user – may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
- Aesthetic and minimalist design: Dialogues should not contain information that is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility
- Help users recognize, diagnose, and recover from errors: Error messages should be expressed in plain language (no codes), precisely indicate the problem, and

[1] This metric assumes that there is an optimal path through the tech. to complete the task, if that is the case then deviations through that process could be noted. This might not necessarily be an error, but would suggest inefficiencies in the system design).

constructively suggest a solution.

- Help and documentation: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation.

Nielsen's Heuristics (Nielsen, 1994): Likely methods include expert review, cognitive walkthrough

Metrics include:

- Visibility of system status: System should always keep users informed about what is going on, through appropriate feedback within reasonable time.
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- Help users recognize, diagnose, and recover from errors: Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
- Help and documentation: Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation.

Usability Survey (Anders et al., 2012): employs a questionnaire methodology, using a 5-point Likert scale and responses to open-ended questions

Metrics include:

- CCS contains information that will be useful to me.
- I am able to perform routine tasks effectively.
- I mastered CCS's major functions in a reasonable amount of time.
- Standard medical language is used throughout CCS.
- I am able to detect when errors are made.
- The interface provides the information and controls necessary to accomplish tasks.
- The way CCS works makes sense to me.
- I would likely choose not to use CCS if given the choice.
- I feel the amount of interaction with CCS is just right.
- My existing knowledge and skills aids me in operating CCS.
- CCS is easy to understand.
- The presentation of information is easy to read.
- The organization of the information in CCS makes sense.
- Most of the people I work with will be able to use CCS the first time they try it.
- CCS enables me to respond effectively to order requests.
- I can tell what CCS is doing at all times.
- I am frustrated when using CCS.
- CCS effectively alerts me to adverse patient conditions.
- CCS enables me to work quickly when I am under time pressure.
- I will recommend that other people in my unit use CCS.
- CCS prompts me in a way that I would expect.
- I am enthusiastic about using CCS.
- I am able to quickly recover when I make an error.
- CCS will change the way I take care of my patients.
- CCS facilitates timely patient care.
- What are your overall impressions of the CCS user interface design?
- What 3 things do you like most about CCS's design, specifically in terms of what you can do in the interface?
- What 3 things do you like least about CCS's design?
- What would you want to change before you were required to use CCS?

The research team's final evaluation metrics plan, to include system requirements, cognitive work support, and clinical outcomes, is planned for completion in time for the first CCS Usability Assessment in December 2014.

Appendix E. Use Cases

User Use Cases

Three use cases illustrate the requirements that have been derived from Phase 1 data. The requirements are shown in blue below each use case. Features that relate to requirements are shown in bold type.

Use Case 1: **Synchronize Patient Care**
Users: Bedside nurse, wound care, RT's, OT's, Charge Nurse

At 0630, a Bedside Nurse has started his preparation for the day **shift** by reviewing information on the patient he is responsible for. Opening CCS, he can see a **roster of patients on the unit**, chooses his patient's **"at-a-glance" view** that shows **recent vital signs, current orders, medications, care plan,** and **notes from the night shift**. He checks the patient's standing **care plan** and **treatment goals** (from Essentris), and **reviews orders** (from CHCS) that are pending as well as the day's **care activities that Wound Care team, RT's, and PT's** have recommended and **what times** they can perform them.

Based on the **night shift note,** the off-going Bedside Nurse entered, he knows the patient will not be ready for what the OT had recommended. He sends a **pre-packaged text** that **will affect the planned OT activity**, recommending that they postpone the treatment. Using the **timeline** in the **patient view**, he slides **RT** and **Wound Care** into slots on the **timeline** to **sequence them.** The OT line item is shown in grey, indicating postponed, and the nurse sends a brief CCS **text message** to the OT that suggests postponing to the next day. The OT and Wound Care sessions are shown in black, indicating accepted. At the same time, CCS displays for **OT, RT**, **Wound Care, resident, and Charge Nurse** reflect that patient's procedure status or time. The lead OT sends a CCS text message that she'll put the procedure on the **proposed care plan** for the following day.

At 10:45, the Bedside Nurse receives a **CCS text message** that the wound care team is delayed because care for a previous patient took longer than planned and the team will be 30 to 45 minutes late. The Bedside Nurse opens the CCS patient timeline, slides the "wound care" session to a later position. She then selects some **pre-packaged text**, and the system **pushes an alert** to the appropriate team members: to the RT letting them know their originally scheduled activity with that patient is going to be pushed back. The **alert** also notifies the burn surgeon letting him know activities are being delayed…so he has a better sense of when dressing will be down for him to examine the patient's wounds.

This use case addresses:

Problem: No effective means to synchronize and adapt different aspects of patient care over the course of a shift, across caregiver team.
Requirement: System shall provide access to a plan of patient care, visible to all caregivers responsible for that patient that includes:

- Current patient status and top-level assessment Goals and priorities for those goals
- Changes/updates (indicating that plan is being updated when one caregiver is working on it) Schedule of activities and any changes, timeline
- Orders and their status
- Identity and contact information for patient's care team

Ideas generated for system features to meet this requirement:

- Visualization of patient schedule for shift (patient x time) (shareable across team)
- The ability to sequence or overlap patient care activities.
- Configurable patient groupings
- Prepackaged text to indicate changes to schedule (e.g., there is ½ hour delay or change in this).
- Sequence, time of activities
- Provide reason for delay, and remedy (using pre-packaged text)
- Overview through time, for unit management.
- Visually connect interdependent events
- Prompt/notify appropriate person when change impacts their activity (e.g. when wound care impacts PT/OT and RT).

Use Case 2: **Order Tracking**
Users: Resident, Charge Nurse, Bedside Nurse, burn surgeon

While team is rounding on a particular patient, a resident selects **patient view** and a **set of previous orders** that are organized in clusters populates the screen. As the attending physician describes what orders to enter the resident **selects the relevant order form screen**. For orders that are not routine, the resident enters the first few letters and **relevant options populate the screen** for selection. She reviews the order set, selects the order option, which is then then highlighted. As the Charge Nurse reads back the attending's directions, the resident verifies selection of orders and submits. After confirming entry, the orders on her screen **indicate date/time stamp**, and also are displayed on screens of the patient's Bedside Nurse, burn surgeon. The team then moves onto next patient. At the end of rounds, the resident realizes that one of the orders had already been entered on the night shift and mentions it to the attending. The attending says "if it's a duplicate then just cancel it." The resident opens the **patient's roster of orders**, selects the order, indicates "delete," and the order type greys out and shows "CANX" and **date/time** stamp.

When checking the **orders status** (from Essentris) the resident had noticed a **tripwire cue** on the display that results for a blood culture taken at 0400 were due back from the lab by 0600. She sends a **prepackaged text message** to the lab to learn where the results are. The order line in the **patient's status page**, which the Bedside Nurse and burn surgeon can also see, indicates a query is pending. Curious as to why that routine lab is late, the burn surgeon opens a more **molar view** that shows **all pending labs** and notices that test is delayed for all BICU patients. Checking by phone with the lab, he finds a failed lab equipment part has slowed throughput, and sends a brief **CCS text note** to all residents and Bedside Nurses to **expect a delay** for that particular test.

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1. Problem: Order entry is often delayed, requiring members of the clinical team to track down residents to remind/ask them to enter orders. Confusion also exists around status of orders (whether in process or complete), whether a new order is redundant with an existing one, or whether an order has been updated/changed.

Requirement: System shall support real-time order entry – e.g., order entry during rounds – to mitigate delays.

System shall enable multiple team members to view, update, track, and process orders from a simple (handheld?) application, available on numerous devices, indicating changes/updates and current status of each order.

Once an order is in process, the system shall provide team members who act on it with a simple, accessible means for annotating their action in the system; the system shall update immediately and push notifications to subscribers

The system shall enable team members to subscribe to push notifications for certain patients about status of in-process orders/labs/procedures.

Ideas generated for system features to meet this requirement:

- Order pick list and window per patient
- Order status
- Notify others if needed (e.g., infections control)
- Provide prompt for delayed order entry (based on programmable timing tripwire)
- Display information required to make decision about order available with the order (the relevant parameters)
- Provide molar/aggregated view of delays for a given patient
- System will track (and possibly highlight) when an order has been changed.
- System will provide timestamp for orders
  (see other category on info staleness and providing timestamps).

2. **Problem:** Lags in updating the information means that information in the system can be stale or inaccurate, causing lack of SA for highly unstable patients.

Requirement:
The system shall allow the clinicians to know/assess whether the information in the system is current or out of date.

Ideas generated for system features to meet this requirement:
- Information should be time stamped (Q: which information in particular?)
- System should highlight recent results – e.g., lab results, cultures. And also highlight orders that are in process. (Q: What else?)
- System should highlight/provide alert when orders are changed.
- System should highlight/alert staff to contraindications. (e.g., patient positioning, nutrition)

3. **Problem:** Lab cultures are lab culture orders are submitted, but requestors are not made aware of status (whether order has been received, whether it's pending, whether it's growing something), including when results are in.., resulting in delay of treatment and other issues.

Requirement: When any tests are ordered (lab, xray, etc.), the system shall provide status update (e.g., order received, in process, completed), and push results notification to requesters and caregivers for that patient.

Ideas generated for system features to meet this requirement:

- System provides news feed from lab about cultures. (Q: are there others?)

Use Case 3: **Trends**
Users: Resident, intensivist, social worker, chaplain, Bedside Nurse, RT, burn surgeon

With a population of 11 patients, staff attention has focused on two patients on the unit who are exceptionally fragile and in need of a great deal of care. The resident and intensivist on call are trying to better understand how one of these patients have been **trending over the last couple weeks**. This is, in order to inform a decision about whether to pursue other treatment options (e.g., more aggressive debridement) or to transition to palliative care. The resident pulls up the patient's **integrated view** that shows **key trend information**, including:

a. **Vital signs** over last 48 hours
b. **Indicators of infection** O2 saturation **n** such as sepsis over last 24-48 hours
c. **Indicators of wound healing** over last 1-2 weeks (with photographic images in the specified timeframe)

After looking at trends, they notify the social worker and chaplain via **CCS text message** that they have decided to talk to the family about transitioning the patient to palliative care.

For the other patient, the burn surgeon, resident, and Bedside Nurse look at the patient's data together to evaluate whether he is ready for another surgery. In the **patient's integrated view**, they **open tabs** to look at more detailed information in key categories:

- Lungs (Respiration, tidal volume, O2 saturation, radiology images possibly indicating pneumonia)
- Cardio/Vascular (blood pressure, arrhythmias, peripheral circulation)
- Hematology (clotting factor)
- Kidney (electrolytes)
- Medications (type, dosage)

They agree the patient is ready for the next procedure. The burn surgeon has the resident open the **patient timeline** and the **OR timeline**, Seeing an opening on the **OR timeline**, he slides the **patient token** onto the open slot. The patient timeline shows a "pending" assignment in the surgeon, resident, Bedside Nurse and the OR views. The surgeon accepts the assignment on **his view timeline**, and the **patient's view timeline** shows "confirmed" in the surgeon, resident, Bedside Nurse and the OR views.

The intensivist wants to see if there are other patients with less severe condition who may be in greater need of attention. The CCS **unit view** shows an indication the **tripwire algorithm** generated that one patient's O2 levels are borderline. Opening the **unit view**, she picks **O2 saturation** as a single variable that can indicate a patient having potential difficulty. One patient's O2 saturation appears to be borderline, and she opens that **patient's individual view**, choosing a **12-day view** of O2 levels. She notes that the patient's O2 levels **over the past week** have been at or just below what she wants to see on that patient. She sends a **CCS text message** to the patient's **resident,** Bedside Nurse, and **RT** asking for a recommendation that would stabilize the patient's O2 levels. Each replies within 15-20 minutes with their view and the intensivist directs the resident via a **CCS text message** to **enter an order** for increased O2 ventilation rate on cannula.

In a routine check of **unit-level trends**, the burn surgeon opens a query in CCS on infections. While infections are well known for the two patients in greatest need, the surgeon also sees a trend of increased tests ordered for a particular pathogen, MRSA, that has been considered routine and limited to the two fragile patients. Shifting the **time scale** for MRSA tests to the **week, the month, and two months**, he sees a significant increase in MRSA **test frequency**. The surgeon sends an email to the infection control team asking for the duty infection control MD to come to the unit and **review the trend**.

---

1. Problem: Caregivers need trend and macro-level information to inform SA, sensemaking and decision making, but this information is not readily available.

Requirement: The system shall provide a time-history of trend information at selectable time scales for key patient measures/parameters (need specifics, which parameters have priority, are they dependent on the patient, etc.).

The system shall provide a top-level dashboard of defined parameters that visually represents each patient's history on those parameters for present day, over the past week, over the past month, and at other time scales.

The system shall show an "at a glance" and role-specific view of which patients are most vulnerable or unstable.

The system should include tripwire algorithms that will flag and notify team of a trending decline or emergent instability in patient health or progress.

Ideas generated for system features to meet this requirement:

a. system should display role-specific trend information in configurable time periods such as 12 hours, 24 hours, 2 weeks.

2. Problem: Lags in updating the information means that information in the system can be stale or inaccurate, causing lack of SA for highly unstable patients.

Requirement:
The system shall allow the clinicians to know/assess whether the information in the system is current or out of date.

Ideas generated for system features to meet this requirement:

a. information should be time stamped (Q: which info in particular?)
b. system should highlight recent results - e.g., lab results, cultures. And also highlight orders that are in process. (Q: What else?)
c. system should highlight/provide alert when orders are changed.
d. system should highlight/alert staff to contraindications. (e.g. patient positioning, nutrition)

Machine Learning Use Cases

We start by defining terms, then provide three use cases that are specific to what the CCS machine learning features will perform.

Definitions

Current Patient: The patient that the CCS user is currently treating.

Condition Point: A span of time during which a patient's condition is evaluated as an aggregate. This may be fixed-time-span-based (a given day, hour, minute), or automatically identified by CCS data analytics (in a yet-to-be-defined developer-level use case).

Final Condition Point: The Condition Point when a patient exits the unit.

Patient Condition: The set of values of all of a patient's relevant data fields, for a given Condition Point. Note that for any given patient, these values may not be fully populated. In addition to vital signs, laboratory results, I/Os, and current treatments, the condition may also include the SOFA score, SAPS 2 score, APACHE III score, and POIP features/treatments scales. This may also include calculated rates of change of variables, and measures of whether they are near to inflection points (aggregated trend information).

Representative Patient Cohort: A set of patients (represented by their Patient Conditions), from the historical record, that are inferred by CCS data analytics to be similar to the Current Patient at the current Condition Point.

Representative Patient Condition: A theoretical (and completely populated) Patient Condition, constructed to best represent the Current Patient at the current Condition Point, based on the Representative Patient Cohort. Note that free-text relevant data fields are populated with statistically relevant words from those fields in records of patients in the Representative Patient Cohort.

Subsequent Representative Patient Condition: A theoretical (and completely populated) Patient Condition, constructed to best represent the Current Patient, based on the subsequent Condition Point (one per patient) for all patients in the Representative Patient Cohort.

Final Representative Patient Condition: A theoretical (and completely populated) Patient Condition, constructed to best represent the Current Patient, based on the Final Condition Points of all patients in the Representative Patient Cohort.

Use Cases

Use Case 1:

Identifying possible and discrepant clinician actions according to patient current condition and predicted trajectory:

- Actors: User, CCS
- The use case begins when the user enters the rounds review widget.
    - **CCS data analytics computes a Representative Patient Cohort and Representative Patient Condition for the Current Patient at the current Condition Point**
    - CCS displays all populated values of the Current Patient's condition in the patient identifier. CCS populates the patient identifier taking into account the

patient's vital signs, laboratory results, I/Os and the current treatments. **Values that are taken from the Current Patient's Condition are displayed as graphically distinct from values taken from the Representative Patient Condition.**

- CCS displays the patient's current orders on the left hand side of the widget. The **recommended orders** are displayed on the right side of the screen.
    - **CCS categorizes the orders,** and displays orders using three colors, one for each of the following categories:
        - Orders that are assigned to both the Representative Patient Cohort and the Current Patient are marked with the same color in both columns.
        - Orders that are assigned to the Representative Patient Cohort but not the Current Patient are highlighted in one color on the right side of screen.
        - Orders that are not assigned to the Representative Patient Cohort but are assigned to the Current Patient are highlighted in another color on the left side of the screen.
- The user can select orders from the current orders list for discontinuation (removed from the patient's task list) or modification (added to the patient's task list) or orders from the **suggested list** (which are then added to the task list).

- The use case ends when the user saves the tasks to the task list and exits the widget.

Sub Use Cases involving the SSCI developer-level use cases:

- Constructing the Representative Patient Cohort
- Constructing the Representative Patient Condition
- Building a list of recommended orders.
- Categorizing recommended orders in a list.
- Determining orders that are similar.

Use Case 2:
Identifying worsening patient.

- Actors: User, CCS
- This use case begins when the user opens CCS and views the patient identifier
    - **CCS data analytics computes a Representative Patient Cohort, Representative Patient Condition, Subsequent Representative Patient Condition, and Final Representative Patient Condition**
    - The user determines if the patient data might be **moving in the wrong direction** (e.g., an inflection point where vital signs are worsening, laboratory results are worsening, or the pattern of current data suggest the patient might get worse in the next 6-12 hours) by viewing the patient identifier.
    - CCS displays **warnings** to the user **that the patient may be getting worse** by changing the color of the patient condition identifier or making it flash.

- This use case ends when the clinician enters the rounds review widget to make changes for the patient

Sub Use Cases involving the SSCI developer-level use cases:

- Determining that a patient may be getting worse.
- Creating a warning that a patient may be getting worse.
- Building a list of warnings.

Use Case 3.
Problem list summary and decision support.

- Actors: User, CCS
- This use case begins when the user views the Problem List within the CCS Patient Summary.
    - The user adds a new problem to the problem list.
    - **CCS data analytics computes a Representative Patient Cohort, Representative Patient Condition, Subsequent Representative Patient Condition, and Final Representative Patient Condition**
    - The CCS system adds entries to the problem list with **suggested problems** (e.g. using the clinician notes, the machine identifies 30% TBSA burns, pneumonia, and heart failure; using the data the machine suggests ARDS – P:F ratio is < 300, PEEP > 5, on the ventilator, CVP < 18).
    - CCS displays clinician entered problems and system **suggested problems** in different colors on the problem list.
    - The user right clicks (or similar design) on the problem and the following options appear:
        - An option to accept or reject the suggested problem.
        - An option to mark the problem resolved.
            - If the user clicks this option, CCS moves it the bottom of the problem list under the heading "resolved" with other problems that are historical.
        - Data associated with this problem.
            - If the user clicks this option, CCS displays **all data used to suggest or is associated with** this problem from the medical record (e.g. ARDS would show the ABG, FiO2, ventilator settings, CXR, notes mentioning this problem, etc.)
- The use case ends when the user stops interacting with the problem list.

Sub Use Cases involving the SSCI developer-level use cases:

- Identifying problems based on the computed representative data.
- Building a list of problems.
- Building a list of medical record data associated with a problem.

Appendix F. Information Design Prototypes

The following illustrations show the information design that evolved from the Phase 1 data, analyses, and requirements. They include: Patient identifier, Patient System's view, Rounds View (including "child-parent" interactive detail), Rehabilitation Therapist view, Unit view, and Family member view.

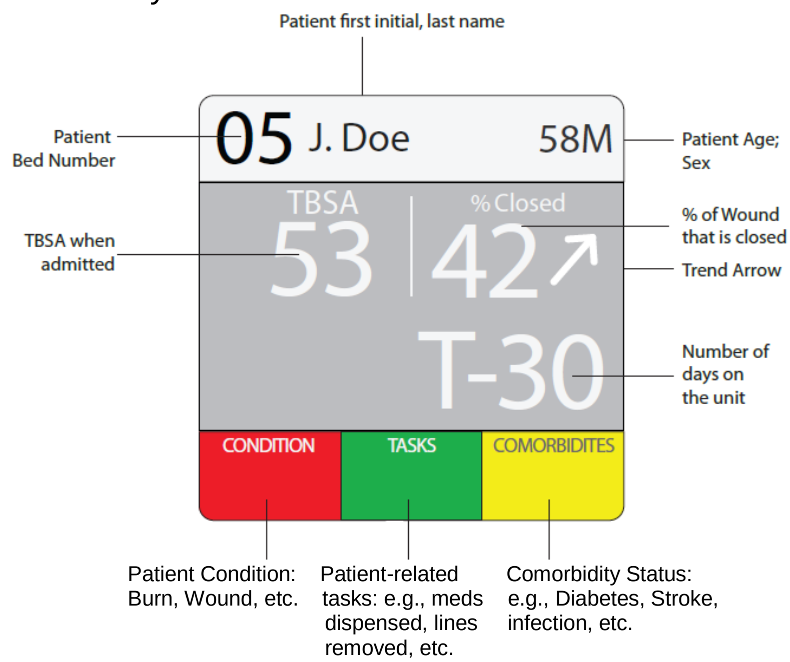

Figure F-1. Patient Identifier

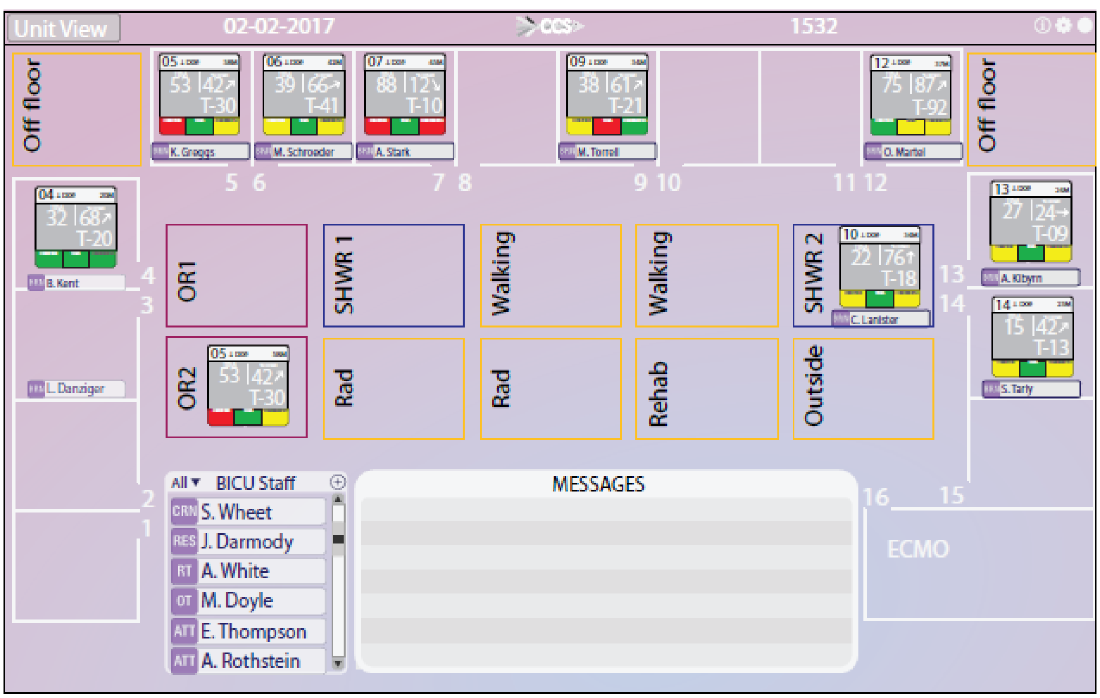

Figure F-2. Unit view.

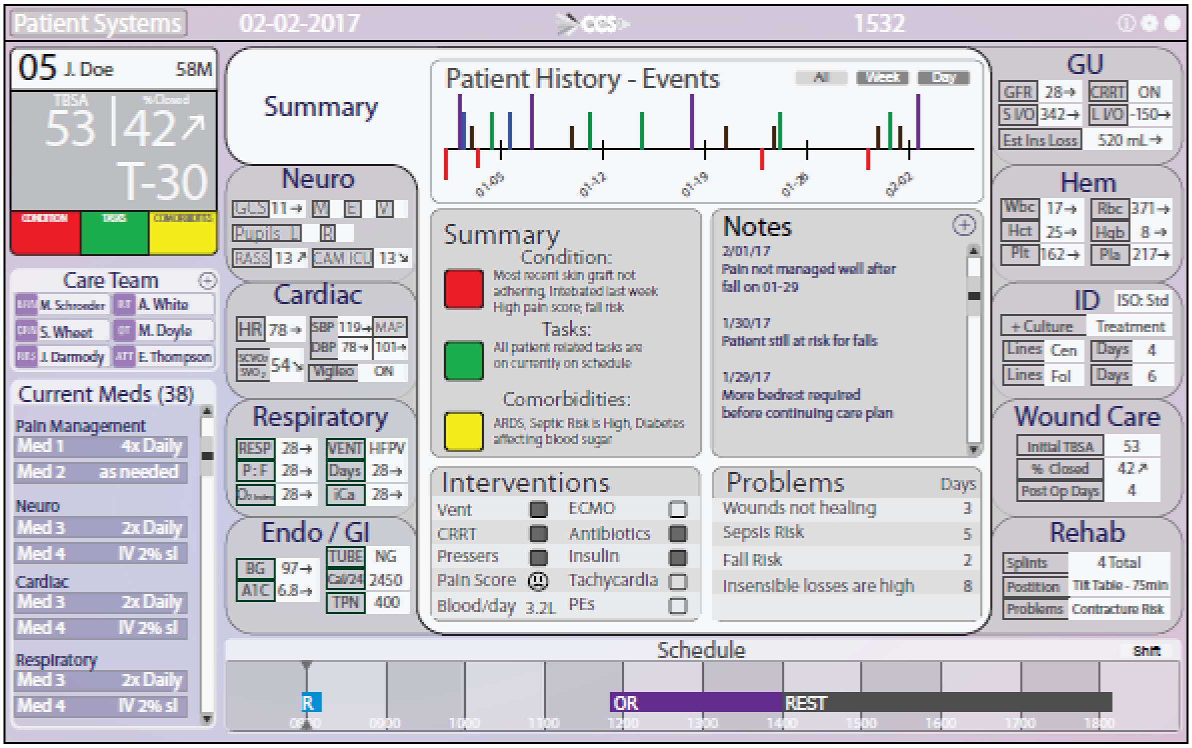

Figure F-3. Patient system's view – overview screen.

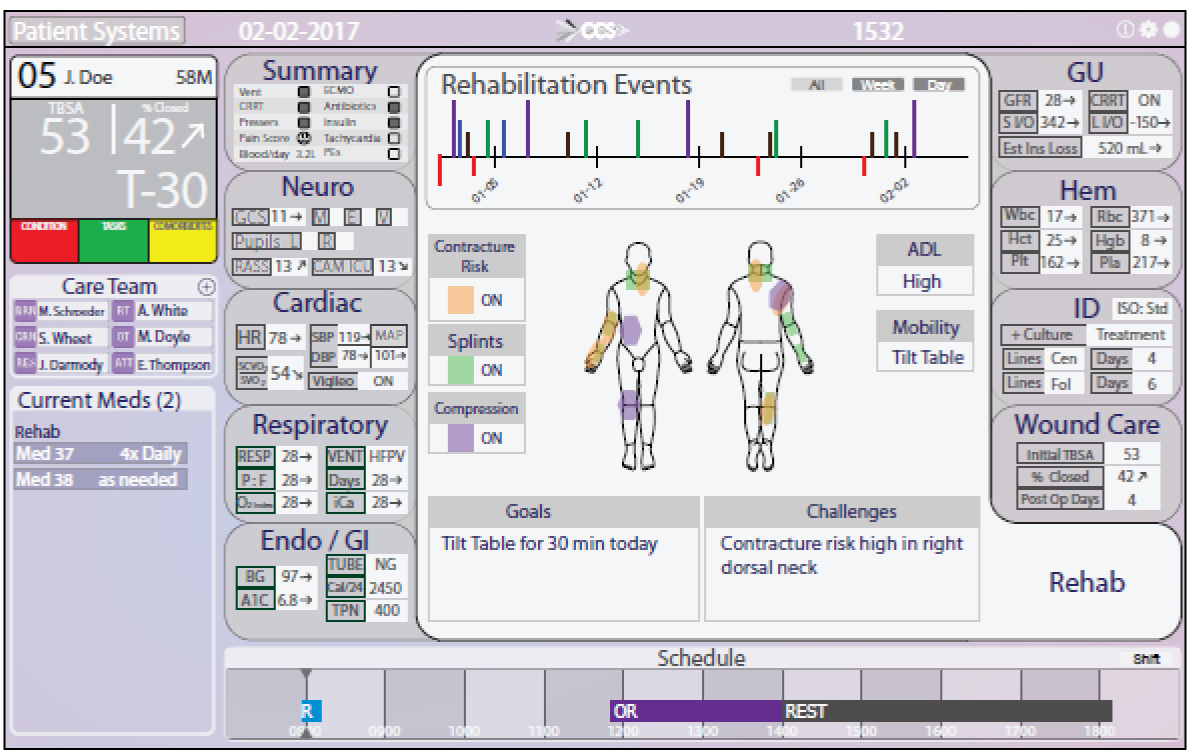

Figure F-4. Patient system's view – rehabilitation.

Figure F-5. Interaction Illustration.

Figure F-6. Rounds View.

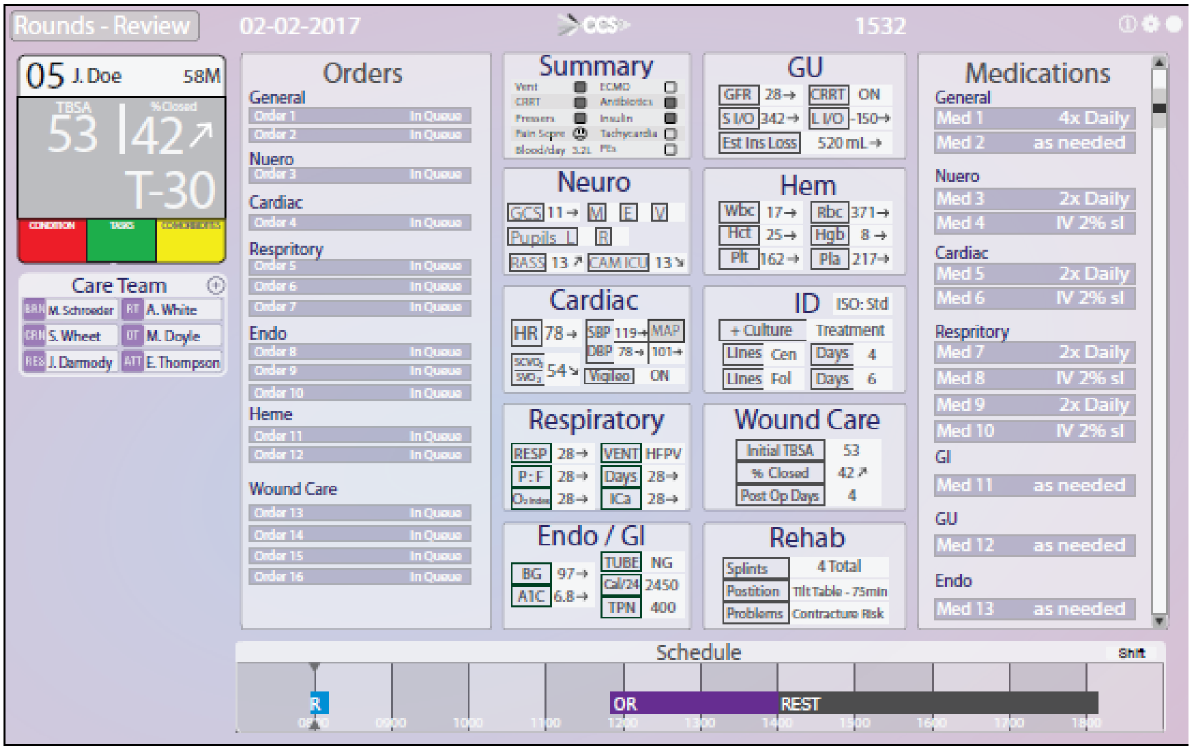

Figure F-7. Rounds Review.

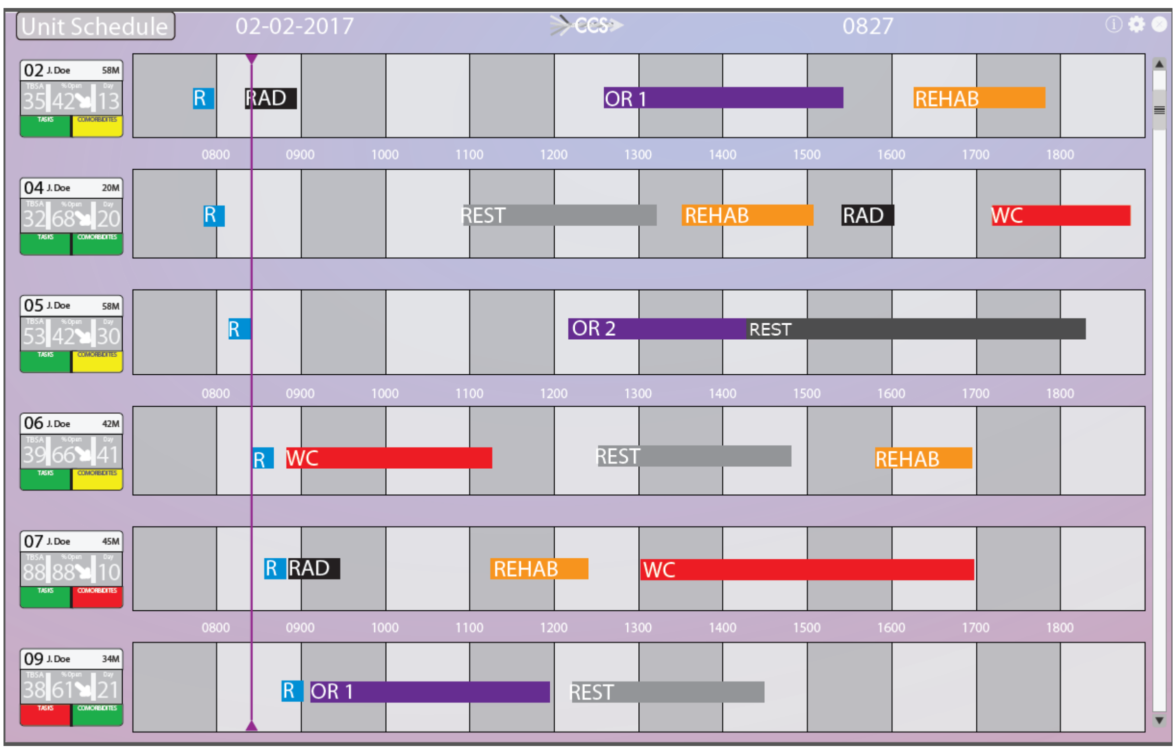

Figure F-8. Patient Schedule Overview.

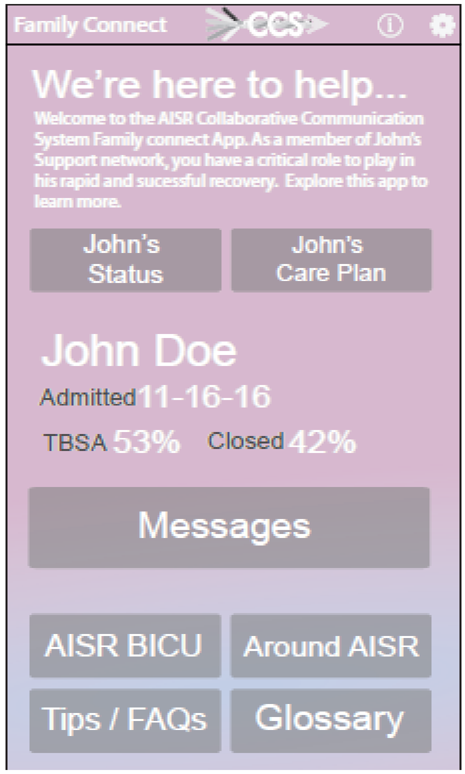

Figure F-9. Family view.

Appendix G. Machine Learning Development Milestones

Pending availability of data from Essentris:

Milestone 1 [01 Aug 14]: Check in of the following features to the CCS repository, developed and tested on SSCI's Synthetic Demo Patient Condition Database:

1. Move consecutive condition points to single record.
2. Update Synthetic Demo Patient Condition Data to make the number of condition points flexible per record.
3. Update the test harness demo to find representative patient cohorts with these changes.

Milestone 2 [01 Aug 14]: Publish draft CCS Data Analytics Interface based on the Notional GUI Design for CCS.

Milestone 3 [29 Aug 14]: Determine (collaboratively with the CCS team) the subset of data fields in Essentris that, for purposes of the prototype, define a condition point.

Milestone 4 [15 Oct 14]: Check in the following features to the CCS repository, developed and tested on Synthetic CCS Patient Condition Database based on specifications in Milestone 3:

1. Represent series of condition points on one record (replicating techniques developed with Synthetic Demo Patient Condition data).
2. Update test harness demo to find representative patient cohorts from the Synthetic CCS Patient Condition Data.
3. Update test harness demo to demonstrate means of addressing the three SSCI-developed user-level use cases.
4. Publish the actual CCS Data Analytics Interface to ARA.

Milestone 5 [15 Oct 14]: Check in the Database Translator that builds a CCS Patient Condition Database from an Essentris Database.

If SSCI receives Sample Essentris De-Identified Data (from the USAISR)*:*

Milestone 6a [22 Oct 14]: Create a full size Scaled-up Synthetic Essentris Database from the Sample De-Identified Database. Test the Database Translator on the Scaled-up Essentris Database.

If SSCI has not received Sample Essentris Data:

Milestone 6b [14 Nov 14]: Test the Database Translator on the Synthetic Essentris Database (SSCI to derive based on the Synthetic CCS Patient Condition Data).

Milestone 7 [1 Dec 14]: Create Synthetic Seeded Patient Condition Database, seeded with statistics from the Complete Essentris Database at the ISR (SSCI to run the Database Translator on the Complete Essentris Database and run CrossCat on the resulting CCS Patient Condition Data to determine statistics; bring statistic back to SSCI and create the Synthetic Seeded Patient Condition Data), and perform test queries to find representative patient cohorts the seeded data.

Milestone 8 [31 Dec 14]: Use the Database Translator on the Complete Essentris Database at the ISR to build a CCS Patient Condition Database, demonstrate finding representative patient cohorts from the CCS Patient Condition Database.

Data Descriptions:

General:

Essentris Database: Multiple patients, raw patient data in Essentris format.

CCS Patient Condition Database: Multiple patients, consecutive patient condition points, in CCS format structured for CrossCat.

Specific:

Synthetic Demo Patient Condition Database: The current demo database.

Synthetic CCS Patient Condition Database: Notional data for all CCS patient condition fields.

Synthetic Seeded Patient Condition Database: Synthetic data for all CCS patient condition fields, created using the CrossCat statistics seed from the Complete Essentris Database at the ISR.

Scaled-up Synthetic Essentris Database: Full-size synthetic Essentris data derived from small, de-identified sample Essentris data.

Synthetic Essentris Database: Full-size synthetic Essentris data derived from the Synthetic CCS Patient Condition Database.

Complete Essentris Database at the ISR: Full-size, actual, identified patient data.

7

Support for ICU Clinician Cognitive Work through CSE

Christopher Nemeth, Shilo Anders, Jeffrey Brown, Anna Grome, Beth Crandall, and Jeremy Pamplin

CONTENTS

Introduction

"...operators pursue goals in complex work domains..." - edits OK?

Cognitive systems engineering (CSE) has been proven to be useful in revealing key aspects of operator behavior as operators pursue goals in complex work domains, providing the foundation for the development of solutions that are ecologically valid. Health care work settings, particularly the intensive care unit, present one of the most challenging work domains for a researcher to study. Cognitive engineering methods (Hollnagel and Woods 1983; Woods and Roth 1988; Roth et al. 2002; Militello et al. 2010) can be applied to understand characteristics of complex work domains such as the ICU as well as the behavior of workers including clinicians and their support staff. The use of CSE methods makes it possible to identify key traits of health care work settings, such as decisions clinicians make, obstacles clinicians face, and initiatives they take to overcome these obstacles in their efforts to restore patients to the best possible health. CSE methods also have the potential to enable workers to better understand their unit's performance and more successfully adapt to unforeseen challenges—in other words, to be *resilient*.

This chapter describes a project using CSE methods that is underway at a burn intensive care unit (BICU) in a major military medical center. This project will develop an ecologically valid computer-based cognitive artifact (Hutchins 2002) that will support individual and clinical team decisions and communication.

Background

The study of health care relies on the use of proven methods by qualified researchers. This is because work at the sharp (operator) end of health care is (among other traits) dense, time-pressured, and complex. Expert workers can find it difficult to be objective observers of their own activities and work settings. Because of this, studying one's own system may yield conclusions that are logical but may also miss deeper issues. Attention in such studies often focuses on a single theme while excluding the many elements that interact with each other to produce a collective result—its context.

For example, *closed claims reviews* that conclude that error elimination will remove "error causes" ignore the complex pressured context that molded each event. It assumes that a claim will contain all of the information that needs to be known about an adverse outcome. It also presumes to know what caused that outcome, that it was caused by an "error," and that its cause can be "eliminated."

Retrospective records review relies on historical documentation in order to draw conclusions about care and its related risks. But records hold little of the context, speculation, deliberation, and complex trade-off decisions that typically mold any significant event.

Voluntary reporting systems have been touted as tools to incorporate error reporting and analysis into the culture of medicine (Plews-Organ et al. 2004). However, voluntary reporting fails to note how the approach is vulnerable to social and organizational influences.

Clinical discussions of patient safety often review how effective a single diagnostic or therapeutic intervention is without taking other factors into account that would affect outcomes in actual practice. For example, Shojania et al. (2001) tested the use of a single item to prevent infections: a maximum sterile barrier when placing intravenous catheters. Some clinicians attempt to make system analysis easier by bounding the problem through selection and management of a single variable. Kyriacou et al. (1999), for example, sought to measure and reduce the length of stay in the emergency department. Some clinicians have applied methods such as workload assessment to the ED, but they found that the level of effort that is required makes it difficult to routinely use it as a measurement tool (Levin et al. 2006). Others have imported measures from other sectors to measure a single aspect of ED operation. For example, France and Levin (2006) used the notion of "system complexity" to determine safe capacity during care demand surges but conceded that phenomena such as interruptions need to be added.

Research that does not adequately detect or understand these issues diverts valuable resources into low-yield efforts. Research that reveals context will grasp the constraints that shape opportunities and risks in practice, curb the influence of hindsight and outcome bias, and yield valid solutions that gain traction in actual work settings (Wears and Nemeth 2007). A current intensive care unit study provides an illustration of how the use of CSE makes that possible.

Research Design and Methods

Our research team is completing the first part of a three-year study to develop a computer-based cognitive aid that supports cognitive work and communication. While it is still in its early stages, it can serve as an example of CSE's value in health care. We discuss the CSE approach in this chapter in the context of our work on a prior project that described quality standards for how to conduct CSE research.

Quality

Nemeth et al. (2011) described the use of CSE in a Navy-funded project that demonstrated how to use the CSE approach in the context of the Department of Defense acquisition process. The project's results would be used by government staff members and contractors who have no prior CSE training or experience. The approach needs to be used well to produce useful results. How would the new users know what that is? The team conceived of "reasonable scientific criteria" as a way to guide new users through CSE in a manner that is scientifically rigorous and that links design recommendations directly to operator needs. Using steps in the CSE process, the team considered the goals and activities at each stage, case studies from the literature that exemplified each stage, and ways that performance and scientific rigor could be evaluated at each stage. In order to do that, the team considered three questions:

- What reliability/validity criteria are important and reasonable to apply to CTA data?
- What are the standards of practice, and what needs to be done to meet those standards?
- How can a rigorous process be created and followed while also being open to discovery with respect to process and outcome?

Answers to these questions identified a set of quality standards for each stage of the CSE process (Table 7.1) from Nemeth et al. (2011) that can also be applied to research in the health care context.

In the section Research Process, we describe how the first three standards have guided our efforts during the project's first year. The standards for "Application: design" and "Evaluation" will guide our work in the project's second and third years.

Research Design

Our project's goal is to improve patient care by better support of the judgment of BICU clinicians and teams by developing a cognitive aid that assists in decision making and communication. The project's three phases are scheduled to take roughly a year apiece for foundation research, cognitive aid prototype development, and prototype assessment. The first-year goal was to develop a thorough description of individual and team cognition that will provide the basis for cognitive aid prototype development in the second year as well as criteria for prototype assessment in the third year.

TABLE 7.1

Reasonable Scientific Criteria for CSE

CSE Step	Standards
1. Preparation and framing	Clear statements of • Issue or problem • Framing activities outcome • Method, settings, project participant selection rationale
2. Knowledge elicitation	Use of multiple knowledge elicitation (KE) methods Use of interview and observation guides Purposeful sampling of participants and settings Qualified prepared data collectors Quality control protocols (specified format to document data) Manage the dual requirements for rigor and flexibility
3. Analysis and representation	Systematic, purposeful, and documented analysis process Audit trail to connect data elements to findings to design elements Multiple analysis processes and multiple passes thru the data Qualified analysis team members Validity checks on findings Goal-driven selection of qualitative versus quantitative analysis Use of reliability indices
4. Application: design	Iterative design–build–evaluate process Subject matter experts (SMEs) for credibility checks Audit trail to connect data elements, to findings, to design
5. Evaluation	Clear assessment criteria Review evaluation results systematically and purposefully Evaluation methods reflect key cognitive components, behaviors Outcomes reflect cognitive and behavioral issues critical for cognitive work Verify whether the design/changes improve performance

"The five member core team members" was changed to "The five core team members". Please check if OK.

The five core team members are experienced in health care field studies using CSE methods and are located remotely from the research site. To manage this, they retained a licensed vocational nurse (LVN) at the site to help with the administrative aspects of research team visits. All data collection and human subject consent were carried out under the jurisdiction of the medical center's Institutional Review Board (IRB), which reviewed and approved the research protocol. In advance of the team's first trip to the site, the Co-PI and LVN obtained the consent of health care team members working in the BICU who were willing to participate in the study. Those who declined to participate were excluded from observations and interviews.

Research Site

The research site is a BICU located in a new wing of a federally funded 450-bed tertiary care military academic medical center. The 16-bed unit is widely considered to be one of the best of its kind in the country. Two of the ICU beds are reserved to serve as a postanesthesia care unit (PACU), and another is dedicated to support the center's extracorporeal membrane oxygenation (ECMO) program. Other nearby units support the ICU, including a step-down unit, dedicated burn operating room, and an outpatient clinic. The typical census averages around 8 patients but has risen to as high as 13 during our study period. This unit's role as a regional tertiary care unit attracts patients who have the most severe affliction from thermal, chemical, mechanical, or electrical burns. It treats patients with burn-like diseases of the skin such as toxic epidermal necrolysis, Stevens–Johnson syndrome, and the autoimmune disorder pemphigus vulgaris. The unit also treats patients with infections or trauma that causes extensive soft tissue damage or loss, such as necrotizing fasciitis, severe degloving injuries, and some war-related trauma. Patient length of stay ranges from days to more than 12 months.

Sample

All clinicians, patients, and patients' friends and family members are potential participants in the study. By the end of the study, we anticipate that over 150 clinicians will be included in the sample. Subjects are recruited through word of mouth in coordination with the BICU medical director and head nurse. Patients in the BICU (or their legal representative) are asked at the start of an observation period to complete a Health Insurance Portability and Accountability Act release before observation or interview. No clinical information collection or recordings are made in the presence of any patient who declines to complete the release. Patient medical data that are necessary to clinical decision making are collected without protected health information and are used only as examples of information that clinicians need to do their work.

Methods

The study of human behavior requires repeated samples to capture its richness, complexity, and variation. No method by itself can account for this complexity. As a result, multiple methods need to be used in order to ensure that the account is valid and as accurate as possible. The research design for this project relies on multiple methods to triangulate data collection and analysis: observation, interviews, and artifact analysis. Comparison of data among all of these sources minimizes the potential bias that a single method may induce.

Observation

In-person observation makes it possible for the research team to witness the phenomena of patient care and team collaboration *in situ*. Informal probe questions enable the researchers to request background and clarifying information in the context of the situation. Observations can be used to study the ways that practitioners perform diagnoses and prepare, launch, monitor, adjust, and complete patient care. The research team performs observations at various times throughout the day and evening to include a range of circumstances and clinicians' responses. Conditions can range from quiet routine to rapid changes. These can happen during the admission or discharge of multiple patients, emergent conditions such as treating rare emergencies like cardiac arrest or burn shock, and common emergencies such as treating postoperative hemodynamic instability.

Observation also includes informal interviews with clinicians as they work in order to learn the bases for their decisions or apparent indecision, motivations, expectations, and preferences that observation alone cannot reveal. Field notes that researchers make during observation provide data for analysis to reveal patterns among and across clinicians. Observations make it possible to describe the ways that individuals and groups cope with complexity and uncertainty. Research team members pay particular attention to heuristics (rules of thumb), and clinicians have developed their expertise and knowledge about individual and system performance, how they use systems such as the electronic health record, mental simulations they perform, and how they assess outcomes. The research team also watches for how the unit members resolve discrepancies and conflicts, negotiate trade-off, evaluate the credibility of data and information from others outside of the unit, and mentor and coach junior members.

During the first visit, team members visited the unit for five weekdays during the day shift (0800–1600). The team scheduled regular observations on the ICU to avoid interfering with clinical work. Subsequent visits to the site also covered evening and night shifts.

Structured Interviews

Cognitive task analysis (CTA) interviews are used to elicit knowledge from clinicians on their background to learn point of view, work activities, information sources on which they rely, and reflections on the challenges they face (Crandall et al. 2006).

Artifact Analysis

Clinicians use cognitive artifacts to capture and share information (Hutchins 2000). These include hard-copy printouts such as sign-out sheets, white marker status boards, and diagnostic and therapeutic equipment displays. They also include personal notes and related items that individuals find helpful, which are not part of the formal information ecology. The research team is collecting de-identified examples of these artifacts that are maintained by and for the group, as well as artifacts that individuals create and use in their work. Both formal and informal artifacts help to understand the inventory of information that the unit develops and uses, which will suggest the content and flow of information that this project's prototype will help to manage.

Research Process

Note that there is no entry in Table 7.1 with the italic font. Please check.

The team began its work by conducting orientation interviews with selected clinicians at the research site. Quality standards described in Table 7.1 that guided our work are shown in italics. The interviews sought information about the BICU in order to develop an interview guide that would be used to organize data collection efforts during field visits. This enabled the team to develop clear statements of the issues and challenges and the outcome of framing activities. Using these, the team could create the rationale for method, settings, and selection of project participants at the research site. Four one-week data collection visits were conducted at the research site every other month, relying on quality control protocols to document interviews and observations, and cross-check the content of data records. Purposeful sampling of participants and settings ensured validity and reliability of the data that were collected during each visit. Each observation period lasted one week and was followed by a refractory period, during which the investigators reviewed notes, recordings, and artifacts. Data analysis results were also used to revise plans and interview guides for later data collection efforts.

Data Collection

A team of four qualified, prepared data collectors traveled to the site for the first data collection visit. They conferred with the Associate PI (located at the research site) on ICU census and plans for clinical activity. Using multiple KE methods to support findings consistency and comprehensiveness, they conducted CTA interviews to account for each role in the clinical care team. They accompanied the clinical team on daily rounds each morning, which were typically held outside of each patient room. During the trip, the team managed the dual requirements for rigor and flexibility by following interview guides, yet taking the opportunity to shadow participants and ask probe questions when the occasion presented itself. The team collected data firsthand by observing the phenomena that occurred while clinicians provided care in the ICU, using the CSE approach to describe the ICU as a work domain and to account for individual and team cognitive activities. They also collected de-identified examples of computer-based and hard-copy artifacts that the staff use in their daily work.

Rounds were recorded using a handheld video camera to capture team interaction and artifact use and were de-identified using a video-editing software. Recordings were made for future reference on how team members use and share information, including reference to artifacts such as sign-out sheets and task lists. When clinicians interacted directly with the patient, the team used audio recordings to capture how information was shared. No video was taken of the patients. When clinicians had time available, two team members conducted a CTA interview following the interview guide that was developed in the initial six months of the project. If the clinicians were not available during the scheduled team visit, the on-site research nurse would help to organize the interview, and the core team members would participate remotely.

Data Analysis

Data are evaluated using goal-driven selection of qualitative vs. quantitative analysis to extract patterns and themes. The research team gathers for data analysis meetings roughly a month after each data collection visit. The team has experience to detect and elicit patterns through a systematic, purposeful, and documented analysis process. Analysis sessions make possible the insight into what matters in the research setting and why it matters by performing checks on findings credibility, consistency, comprehensiveness, and centrality.

"Analysis sessions make possible the insight into what matters in the research setting..." - edits OK?

Team members prepare by reviewing the data collected from the most recent visit to ensure that each member has a current accurate recollection. This may also include organizing the data and checking to make sure that they are complete and ready to be analyzed. Members assemble as a group in 2–3 day-long sessions over a week to discover what the data mean by looking for central questions, issues, and themes. For example, the interview guide sought information on how team members manage work flow. Data analysis discussion explored observation notes and interview responses for items related to workflow.

The analysis sessions are intense sense-making exercises that use multiple analysis processes and make multiple passes through the data. Qualified team members use interview notes, observation notes, and artifacts to find patterns and themes in the collected data using reliability indices such as intercoder reliability (when and if they are appropriate). The team also looks for related themes, such as whether there is evidence among the data that show how the clinicians identify and reconcile goal conflicts or resolve agendas that do not agree. Team members suggest themes or patterns that seem to occur in the data. Others challenge, modify, or add to the discussion to ensure validity checks on findings. Team members create diagrams, tables, timelines, and storyboards and use other visualization methods to pose, assemble, and reassemble relationships in order to recognize possible patterns among and across data. During these free-flowing exchanges, new insights rapidly evolve and take the team to a new level of understanding.

Keeping track of the logic trail during these sessions can be a challenge. Maintaining the logical connection from data through analyses matters, because each of the requirements that the analyses eventually produce must have a deliberate link to the data from which they were derived. To keep track of these relationships, the team keeps notes that maintain an audit trail to connect data elements to findings to design elements. Without this structure, it is easy to disregard the data, producing a result that is not a set of findings but rather a collective team impression.

By the end of the analysis sessions, the team has deepened their understanding of what they know about the work setting and what occurs there. They also have a clearer sense of what isn't known yet and needs to be included in the plan for the next site visit. Later in the year, further analysis work will code and analyze all interview and observation data to detect themes and barriers and produce requirements for the prototype.

Limitations

Modest project funding made it necessary to study one site, which limits its reliability. The research team was not available on the unit continuously during the study, making it difficult to observe momentary changes in unit activity such as clinician responses to codes. To mitigate that limitation, the research nurse was available at the research site to collect data in the periods between research team visits.

Preliminary Findings

While the project has only been underway for a brief time, the first data collection and analysis sessions made it possible to describe initial findings that include unit activity, the network of care providers, and information sources on which the clinicians rely. These elements amount to an initial inventory of the work setting that the team can build on during subsequent site visits.

Unit Activity

While many activities occur on the unit through 24 h, Table 7.2 shows the essential events that occur regularly each day. Those who are involved in these activities and the information resources they use to perform them start to flesh out a description of the unit.

Through the evening, the bedside nurse and resident both monitor and occasionally provide medication to the patient assigned to their care. From 6:30 to 8:00 a.m., the residents and medical students examine the patients and prepare for formal multidisciplinary rounds. The Assistant Chief Nurse and oncoming bedside nurses hold a safety huddle. Off-going and oncoming bedside nurses review their patient's condition and conduct a handoff. The ICU Chief Nurse reviews the unit population and resource needs, and the unit dietician reviews patient nutrition plans. At 8:00 a.m., the general rounds begin and can last up to two or more hours depending on a number of factors including unit census, patients' condition, and time pressure. From 8:00 a.m. to 2:00 p.m., patients are showered, receive care for their wounds, or are taken to the nearby operating room procedures such as tissue debridement, skin grafting,

TABLE 7.2

BICU Schematic Timeline—Weekdays

Time	Activity	Participants	Information Resource
0000–0645	Patient monitoring, occasional medication	Bedside nurse; resident	Patient monitors
0630–0800	Patient exam, rounds preparation	Resident, medical student	Sign-out sheet; patient health record (PHR), wound flow, radiology images; patient monitors; bedside nurse, off-going resident
0645–0700	Safety huddle	Assistant Chief Nurse, oncoming bedside nurses	Personal notes
0700–0800	Bedside report and physical assessment	Off-going bedside nurse, oncoming bedside nurse	Patient monitors
0700	ICU audit	Assistant Chief Nurse	Personal notes
0700–0730	Metabolic assessment	Dietitian	Excel file; PHR
0800	Patient rounds	Intensivist, burn surgeon, fellow, resident, bedside nurse, charge nurse, medical student, respiratory therapist, occupational therapist, social worker, dietician, psychiatrist	PHR
0800–1400	Shower, wound care	Bedside nurse, wound care team: RN and LVN	Wound flow
0800–1400	Medications	Bedside nurse	
0800–1400	Surgeries	Burn surgeon, OR team	Shadow charts
~1400	Patient exam	Resident	
1200–1300	Lecture	Staff physician, surgical and medical residents, medical students	
~1500	Afternoon rounds		
1530	Plan for wound care the next day	Charge nurse, wound care coordinator	4T assignments sheet

and reconstructive surgery. The remainder of the day includes a lecture for residents/medical students, the resident examination of his/her patient, brief afternoon rounds to review what has been completed from tasks assigned during morning rounds, and an informal discussion between the wound care team leader and the charge nurse to decide patient plans for the next day.

Network

Patients on this BICU typically need care by a variety of specialists, requiring exceptional planning, coordination, and ability to work together. Table 7.3

TABLE 7.3

BICU Patient and Patient Care Staff Roles

Patient	Bedside Nurse	Patient Family	Attending Intensivist	Burn Surgeon	Licensed Social Worker
Head nurse	Occupational therapist	Respiratory therapist	Resident	Medical student	Clinical nurse specialist
ICU nurse	Psychiatric nurse	Unit clerk	ICU director	Charge nurse	Pharmacist
Staff psychiatric nurse practitioner					

depicts many of the roles that need to collaborate to create and manage a feasible plan for patient care across multiple shifts through the week and the weekend. The roles range from the bedside nurse, who serves as a primary care provider and kind of the gatekeeper for patient care by others, to primary care physicians such as the intensivist and burn surgeon, and care specialists such as the respiratory and occupational therapists, those who care for members of the health care team such as the psychiatric nurse practitioner, managers who assist with planning and oversight, and hospital employees off the BICU such as the pharmacist. In a unit that involves as many team members and specialties as this BICU, it can help to focus on a single most important element of the work domain. In this unit, the bedside nurse is closest to the patient and can serve as a focus of attention for the researcher to understand crucial working relationships. Figure 7.1 represents the 31 working relationships in our data that the bedside nurse maintains in daily practice. Among all of these roles, the bedside nurse interacts most with others on the nursing staff, the patients' family and friends, physicians (including physicians of different levels of training and of different specialties), rehabilitation/occupational therapy technicians, and the clinical lab and blood bank.

Information Resources

Prior work by researchers including Xiao et al. (2001), Wears et al. (2007), Nemeth et al. (2006), and Bisantz et al. (2010) has described the role of cognitive artifacts (Hutchins 2000) in the health care setting. These artifacts include physical items that are either personal (e.g., a sign-out sheet or note on a scrap of paper) or informal and used by a group (e.g., marker board), as well as electronic information displays that are local (e.g., equipment information display) or distributed (e.g., information system display; electronic medical record). Figure 7.2 depicts many of the artifacts that the staff relies on to perform individual and team cognitive work each day.

Databases and interfaces to manage them include the PHR, outpatient record, blood glucose management, laboratory culture, nurse scheduling, and radiology images. While used in concert, many of these systems are

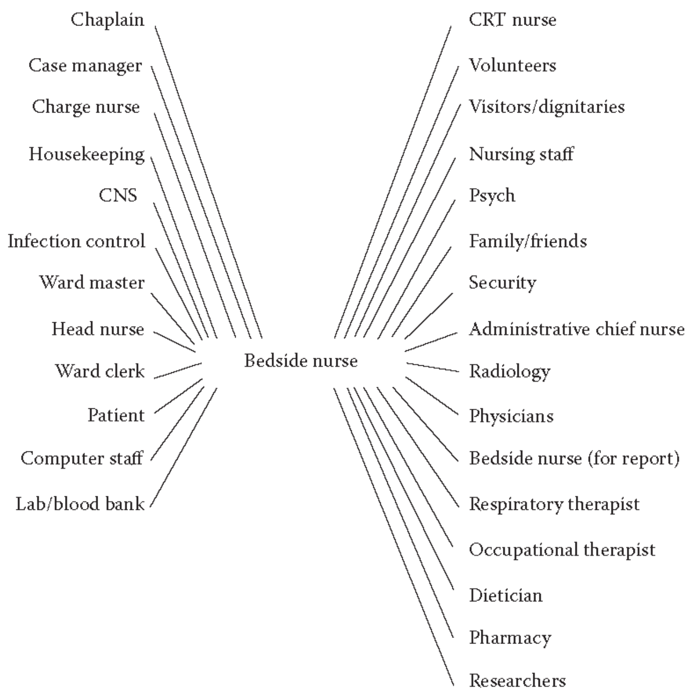

FIGURE 7.1
Initial representation of bedside nurse work relationships. (Copyright © 2013 Applied Research Associates, Inc.)

actually separate. This separation requires care team members to take extra steps and make temporary hard-copy notes to use and transfer information among systems. Other information resources beyond databases include white boards, a daily wound care plan, vital signs flow list, email/cell phone roster, landline phone roster, resident sign-out sheet, and a charge nurse checklist. The strong emphasis on research at the project site has made it possible for clinicians to develop their own formal electronic information sources in addition to the hard-copy artifacts that may be found at other health care locations. The Wound Flow software program makes it possible to identify the location and condition of tissue injury and skin grafts. An Excel file that the unit dietitian has developed makes it possible to accurately track the quality and amount of nutrition that is crucial for burn patient recovery. The Burn Resuscitation Decision Support software enables the staff to accurately manage fluid resuscitation during the critical 48 h following a significant burn injury. The solution that this project creates will need to bring these various parts of this information ecology (Nemeth et al. 2008) together in order to form a cohesive whole for the unit to use. We expect

The entry "Nemeth et al. 2008" is not included in the reference list. Please provide missing information in the references.

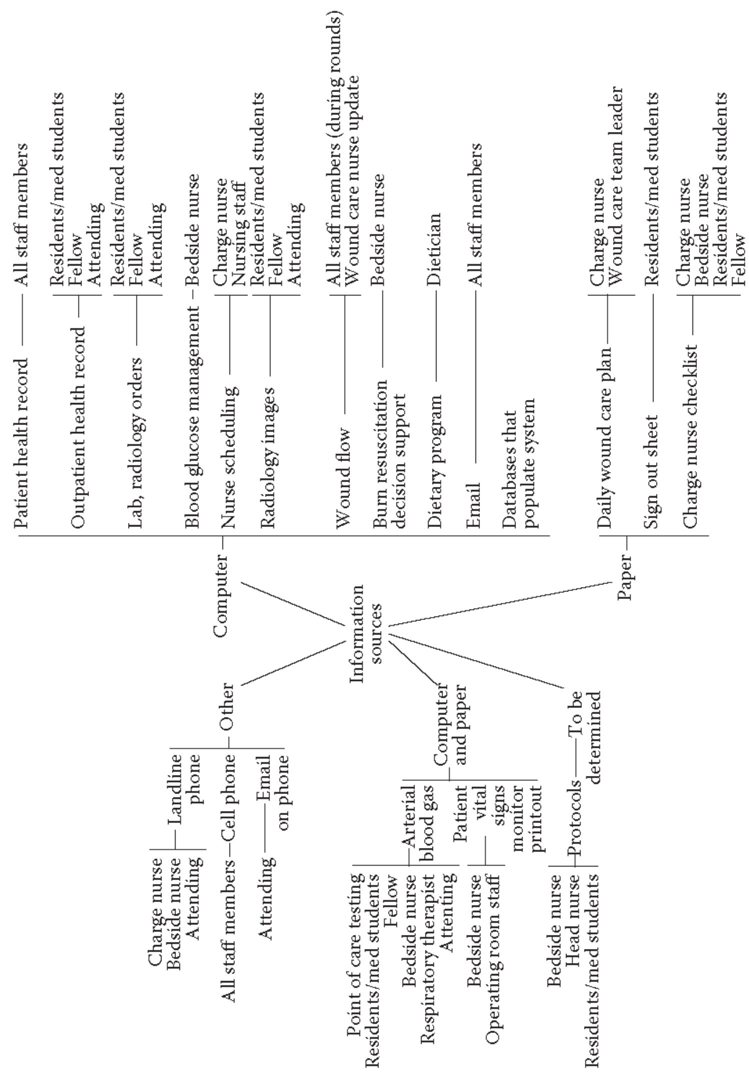

FIGURE 7.2
Information sources that the BICU care providers use. (Copyright © 2013 Applied Research Associates, Inc.)

that using the cognitive aid will enable the unit staff to work together more effectively and efficiently and, as a result, improve patient care effectiveness and outcomes.

Cognitive Work

An initial review of the data indicates that individuals and teams perform a number of macrocognitive (Crandall et al. 2006) activities, which are summarized in Table 7.4. The staff performs *rework* through bridging and work-around strategies to link systems that don't talk to each other in an effort to ensure *information continuity*. For example, the ABG unit is not connected to the database for the electronic PHR. (See Chapter 6 for additional examples, and a proposed model, for tracking ways that information is maintained throughout health care systems.) The dynamic activities on the unit require *negotiation* hourly/by shift/daily among individuals, specialties, and those who have different levels of expertise. *Allocation of resources requires planning and replanning* among and across patients and specialties in *anticipation* of the patient status and needs, and how to meet them through preparation and participation in events.

"Allocation of resources requires planning and replanning among and across patients and specialties in anticipation of the patient status and needs, and how to meet them through preparation and participation in events." - edits OK?

TABLE 7.4

Emergent Themes for Cognitive Work of Burn ICU

Theme	Definition
Rework	Bridging and work-around strategies to link systems that don't talk to each other.
Information continuity	Arterial blood gas (ABG) does/doesn't connect to electronic PHR. An additional volume needs to be created for a very long term care patient.
Negotiation	Among individuals and care specialties, team member levels of knowledge and expertise are dynamic, which requires negotiation by the hour, shift, and day.
Scheduling	Planning and replanning among and across specialties.
Anticipation	Patient status, needs, and how to meet them; preparation and participation in events.
Coordination	Collaboration requires expression of expectations, prioritization, agreement, and recruitment/transfers.
Clarification	Inquiry, sense making, common grounding, to drive down levels of uncertainty and reach an acceptable level of confidence.
Resources	Access, availability, permission, provision, preparation, authority, certification, and use related to equipment, medications, and supplies.
Tasking	Assignment of ICT team members to best match patient needs; based on individual abilities and experience and team needs.
Cross-checking	Identify, confirm, and correct information; problem detection, which may create drag in completing care activities.
Tracking	Account for what needs to be done, whether it has been completed, and what remains to be done.
Gaps	The ability some more experienced team members have to suspect something that is needed is missing.

Collaboration requires the expression of expectations, prioritization, and agreement for staff member recruitment and patient transfers. In order to reach threshold of confidence with which they are comfortable, staff members *clarify* through inquiry, sense making, and seeking common care by reducing uncertainty. Use of *resources* such as equipment depends on its availability as well as permission, provision, preparation, authority, and any required certification to use them. These traits fit what Cook and Woods (2002) have described as the "technical work" in the context of health care. *Tasking* assigns ICU staff members to best match individual abilities/experience and team needs to meet patient needs. Through *cross-checking*, the staff detects problems and identifies, confirms, and corrects information. Their *tracking* efforts account for what needs to be done, whether it has been completed, and what remains to be done. Staff members with the greatest expertise are able to see "gaps," which are, in effect, "what isn't there" but should be.

Challenges

A number of work domain issues shown in Table 7.5 can detract from the time and effort that could be devoted to patient care. Our project team considers each issue from the viewpoint of whether the cognitive aid could help to either mitigate or eliminate them. Nurses fill gaps in the *limited orientation* that residents and float (off unit) nurses receive, which takes time from patient care. Due to *lags in information* timing of information on labs and blood cultures, staff members need to rely on verbal orders (referred to as "on the sly") that are not fully socialized or shared and can result in care delays. *Bedside nurses reconcile conflicts between* patient care needs and technology protocols, guidelines, policy, and regulations. *Procedural drag* results from the need for transcription and work-arounds due to system organizational gaps. The need for clinician *reliance on memory* provides the researcher with a marker for failure, as technology fails to support the needed work. *The long-term story of the patient/big picture is lost*, because trend information and understanding are lost or degraded over a long term of care. *Reliance on verbal exchanges* makes the flow of information porous, brittle, erratically shared, and less reliable. The *authority gradient* between junior and more senior staff members encourages passivity with regard to concerns and impedes sharing. *Common grounding accuracy* suffers from underspecification, requiring confirmation, verification, and clarification. It is not always clear *who has the "Con?"* (has the lead) among specialists during procedures when care quality is high, but no individual takes accountability to assure results. *Timing* issues can result in poor coordination and stale information, such as when a procedure was performed. Without *salience* to bring it to the clinician's attention, important patient information such as "stat" orders is lost in homogenous information displays. Software *usability/access/usefulness* issues result in difficulties in being able to use it, having the knowledge it

TABLE 7.5

Emergent Themes of Barriers and Challenges to Effective Care

Issue	Definition
Limited orientation	Residents and float RNs receive limited orientation to the unit. RNs provide orientation, which takes time from patient care.
Lags in information, medications, labs, and blood	Reliance on verbal orders "on the sly" (informally) that are not fully socialized or shared; creates consistent care delays.
Bedside nurse reconciles conflicts	Technology protocol, guidelines, policy, regulations, and patient care needs require choices to be made.
Procedural drag	The need to create work-arounds and bridging tactics to fill the gap between incompatible systems slows down work efficiency.
Reliance on memory as a failure marker	Technology fails to support necessary work, causing clinicians to rely on memory for continuity (e.g., action items not completed by afternoon rounds not carried through to the next day).
Story of the patient/ big picture is lost	Incremental views of patient status are not synthesized into a whole picture; particular concern for patients in BICU for extended periods.
Reliance on verbal exchanges	Information flow is porous, brittle, not shared, or reliable.
Authority gradient	Encourages passivity with respect to expressing concerns.
Common grounding accuracy	Under specification, needs for confirmation, verification, clarification all affect ability of clinicians to develop consensus.
Action/who has the "Con?"	Numerous well-qualified clinical specialties collaborate but lack of clarity regarding who is leading a particular procedure (e.g., ECMO).
Timing	Lack of synchrony can result in stale information (e.g., when the procedure was performed).
Salience	Great deal of information that is presented homogenously. Information that is most relevant is difficult to find (e.g., "Stat" orders are not evident).
Usability/access/ usefulness	Systems cannot be used without requisite operator knowledge, certain access requirements.
Organizational issues = drag	Compliance with administrative reminders detracts from patient care.

requires to use it, and being able to enter data accurately. Compliance with *organizational issues* such as administrative reminders creates drag for clinician efficiency.

Discussion

The ICU Work Setting

ICU patients present clinical teams with unique challenges and complex combinations of life-threatening injuries and illnesses. Care for this patient population is necessarily multidisciplinary and includes many specialties. Care providers across these clinical areas must collaborate to develop treatment plans, assess progress, and refine or change treatment plans and modes.

Clinician decisions are only as good as the information that is available when they are made. The daily work on the unit requires representations that serve as a map of the ever-changing environment of work that must be successfully navigated. Clinical teams that care for ICU patients in the military health care system encounter these challenges as they make diagnostic and therapeutic decisions and share them with colleagues. Decision-making difficulty increases as the number of patients and the severity of their conditions increase. Complexity grows as the number of care providers seeks to make their own unique contribution to a patient's care.

Patient care activities rely on the acquisition, portrayal, and analysis of therapeutic and diagnostic information from many sources. This creates a complex work setting that is composed of multiple independent agents. All interact in various ways according to inconsistent rules in an attempt to adapt to changing conditions. Because of this, the organization's outcomes are unpredictable, but they often follow predictable patterns (Plsek and Greenhalgh 2001).

Other ethnographic studies also revealed insights into acute care settings. For example, Fackler et al. (2009) used CTA to identify cognitive aspects of critical care practice in two academic ICUs and identified broad categories of cognitive activity: pattern recognition; uncertainty management; strategic vs. tactical thinking; team coordination and maintenance of common ground; and creation and transfer of meaning through stories. Anders et al. (2012) used a simulator-based experiment to evaluate ICU nurses' ability to detect patient changes using an integrated graphical information display (IGID) compared with a conventional electronic chart-style ICU patient information display. The study found that the 32 ICU nurse samples reported more important physiological information with the novel IGID compared with the tabular display and concluded that information displays should accommodate the diversity of those who are intended to use it.

Novak et al. (2012) found that medication administration intersects with other organizational routines, and IT-enabled changes to one routine lead to unintended consequences in its intersection with others. Introducing IT can be improved by nurses who provide technology-use mediation before and after the rollout of a new health IT system. Their efforts can help others to better understand the relationship between IT introduction and changes in routines.

In addition to operational complexity, our research into reporting health care adverse events using CSE methods (Nemeth et al. 2006) has also revealed technical, social, political, and legal forces. Each influences acute care settings such as the ICU, which are typically uncertain, interrupt driven, saturated, and contingent.

Uncertain: Clinicians must treat widely varying patient populations. Time pressure can force clinicians to make decisions based on information that can be insufficient or ambiguous. Field studies using CSE methods can discover initiatives that clinicians have developed to minimize uncertainty.

Interrupt driven: Interruptions create breaks in clinicians' task-oriented work (Chisholm et al. 2000), and when they occur during diagnosis and treatment, they can degrade or defeat attempts to treat patients. Work domain study using CSE methods can identify gaps in care continuity, detect how clinicians allocate limited attention reserves, and produce tools such as cognitive artifacts that maximize patient care opportunities.

Saturated: Facilities and staffs typically run at or near capacity. With little margin of time or resources to spare, clinicians have to develop strategies to cope with variations in care demand. Work domain studies using CSE can reveal discontinuities that exist in the match between resources and demand, such as late shifts, and unexpected surges in care demand.

Contingent: The process of care depends on the patient, including presenting symptoms, documentation of history, response to therapy, expected trajectory of treatment, compliance, and more. CSE methods can be used to discover how care providers create, monitor, and adjust multiple contingencies in order to achieve as satisfactory and expedient an outcome as possible for patients.

In addition, distraction, complexity, remote influences, and consideration make health care human subjects research a particular challenge.

Distraction: Many activities are performed by a variety of clinicians in the vicinity of each other. This makes it easy to be distracted by phenomena that are not necessarily key features of the work domain.

Complexity: Acute care settings have many complex activities that occur at the same time. This is particularly true in an ICU.

Remote influences: Care team members can be distributed across various locations and across time. Not all activity that matters occurs within view or in the immediate recall of those whom the researcher interviews.

Consideration: Patients in the BICU are typically fragile as a result of some trauma. This calls for the researcher to have an adequate sensitivity to care providers, patients, and the patient's family members.

All of these influences form the context in which clinicians perform their cognitive work. The CSE approach makes it possible to describe the domain and individual and team activity in it to transform findings into requirements that serve as the basis for a prototype cognitive aid.

Communication among Care Team Members

Team communication creates, and is created by, the work context. CSE can be used to reveal the context and worker behaviors that lead to understanding communication needs and how to support them. This contrasts with the more traditional information engineering approach that assumes that understanding comes simply from the faithful uninterrupted transmission of data (Feldman and March 1981; Stohl and Redding 1987). Care provider expectations differ on communication content, form, relevance, and value of its completeness.

Interventions based on CSE methods can benefit team communication. For example, Grome et al. (2009) found that co-creative development workshop helped surgical team representatives to create and adapt preoperative briefing content and structure, as well as measures to assess the briefing's effect on teamwork, communication, and patient safety.

The entry "Nemeth and Cook (2013)" is not included in the reference list. Please provide missing information in the references.

Nemeth and Cook (2013) used CSE to identify barriers that can erode the quality and reliability of health care communication that this project addresses.

Difficulties in communication. Health care and the information that is needed to provide it are typically complex and demand accuracy in order to avoid misinterpretation.

Confusion of responsibility. Interwoven relationships among care providers, units, departments, and institutions can result in confusion over who is responsible for a patient's care.

Lack of, or variable availability of, good information resources. Even with sophisticated information technology available, system failure or incompatibility can result in images and reports being mislabeled, misunderstood, swapped, late, misidentified, or unavailable.

Work environment pressures. Care provider efforts to cope with workload demands and time pressure can result in a kind of "shorthand" that edits information in order to be efficient.

Lack of standards or training. Clinical specialties and institutions can vary in the way they go about practices such as handoffs, resulting in the potential for misperception.

Aptitude. Patients and family members may find it hard to understand the information that is conveyed through written, verbal, and graphic health care communication.

Attention. Understanding and context are essential to effective communication. Simple transmission (e.g., a "data dump") does not guarantee that others understand what is provided or can correctly put it into context.

Attitude. Clinician empathy may yield a number of benefits, including patients reporting more about their symptoms and concerns, increased physician diagnostic accuracy, patients receiving more illness-specific information, increased patient participation and education, increased patient compliance and satisfaction, greater patient enablement, and reduced patient emotional distress.

Reader et al. (2008) found that team structure and individual roles and stature have significant effect on ICU communication, and a difference in status appears to influence how communication is perceived. The "authority gradient" barrier mentioned in Table 7.5 may be related to this issue.

Through the use of CSE, the cognitive aid that this project produces will need to help the ICU staff to overcome these potential barriers.

The Role of CSE

The use of CSE methods makes it possible for the researcher to "get in" at the right level of detail. Too general a study will miss the nuances and refinements that clinicians create in order to make their work possible. Too detailed a study may collect great amounts of data but will also miss the broader patterns that make insight possible. Studies of such a complex domain require repeated visits in order to reveal the deeper aspects of what occurs. These are what have been referred to as the "messy details" of technical work (Nemeth et al. 2004). The researcher needs to learn about real-world settings that involve the organized activities of daily life (Garfinkel 1967). Real-world settings are stubborn, though, and do not easily reveal themselves (Blumer 1969).

Research can be basic (a search for general principles), applied (adapting general findings to classes of problems), or clinical (related to specific cases). Most design research is clinical because time and budget allow for little else (Friedman 2000). CSE methods can be used to negotiate the gap between applied and clinical research.

CSE in Health Care

Recent work on collaboration has produced distributed cognition and joint cognitive system models that can be used to better understand health care as a collective enterprise. The use of CSE to identify and describe all ICU elements, including clinicians, information, and artifacts, can identify system gaps. Addressing gaps can lead to authentic improvement in performance and outcomes. For this reason, CSE is particularly well suited to the discovery of phenomena in complex real-world settings.

The entry "Hutchins 1995" is not included in the reference list. Please provide missing information in the references.

Distributed cognition (Hutchins 1995) is the interaction of individuals, artifacts, and the environment. Practitioners must rely on this to prevent the formation of gaps in the continuity of care (Cook et al. 2000). This includes transfers between departments, work-cycle shift changes, and information exchanges among professionals from different fields of practice. Clinicians in an ICU comprise a joint cognitive system that can modify its behavior and decision making on the basis of experience in order to maintain order (Hollnagel and Woods 1983). The daily work of the clinician requires representations that serve as a map of the ever-changing environment of work that must be successfully navigated (Rasmussen et al. 1994). Individual elements of information vary enormously in the length of time that they are reliable, and their value depends on their context. What is represented and how it is represented should depend on the cognitive work it is intended to

"Practitioners must rely on this to prevent the formation of gaps in the continuity of care (Cook et al. 2000)." Edits ok?

support. Furthermore, the partial and overlapping interaction among clinical specialties in the ICU lends itself to additional gaps in care continuity and the misadventures that can result.

Validity

Nemeth et al. (2011) recommended four ways to verify whether results from qualitative studies such as this ICU research project are valid. Findings must be credible, consistent, comprehensive, and central.

Credible. Do findings "ring true" to SMEs and others who work in the domain?

Consistent. Do findings replicate across interviews and across incidents?

Comprehensive. How general are the findings? To what range of tasks and settings do they apply? Can boundaries be identified, and can those limitations be stated?

Central. Do findings speak to cognitive issues that *matter* for performance based on SME judgments, research literature, and other sources?

Studies that meet these criteria are more likely to pass validity tests when solutions are evaluated.

Aspects of Resilience

Knowledge gained through the use of CSE about the nature of work as it is actually done can help to contribute to the system's ability to adapt when confronted with unforeseen challenges—to be more *resilient* (Hollnagel et al. 2006). Recent writing in resilience engineering has identified a number of system characteristics that contribute to system resilience. This knowledge can improve their ability to operate despite significant challenges such as changes in the type, rate, and volume of care. Three characteristics that CSE can assist include being self-aware, the ability to identify and apply resources, and the ability to adapt to surprise.

Self-Aware

The "cottage industry structure of the national healthcare delivery system" results in "disconnected silos of function and specialization."(Reid et al. 2005, pp. 12–13) Acute and ambulatory care patients require coordinated care that is provided by multiple distributed care providers. Their care also calls for the coordination and integration of many functions and specialized areas of knowledge over time. Yet connectivity, integrated care, and coordination are inadequate nationwide at all stages of illness treatment. An estimated 60 million patients in the United States suffer from two or more chronic

The entry "Reid et al. 2005" is not included in the reference list. Please provide missing information in the references.

conditions and are particularly affected by the disconnection among clinical care specialties. The ability to reveal the nature of work domains by using CSE can start to mitigate this significant and widespread issue.

Able to Identify and Apply Resources

Skills, supplies, equipment, and facilities are routinely assembled to perform each procedure. CSE can be used to document work processes and what influences them. That can lead to insight into how these configurations are developed and managed, what goes well, and where misadventures can occur.

Able to Adapt to Surprise

We have shown in prior publications (Nemeth et al. 2007; Cook and Nemeth 2010) how health care organizations respond to events, particularly misadventures. More often than not, the response attempts to isolate the cause and declare that it will not happen again. These efforts stop the exposure to risk. However, they also stop the learning that can inform us how systems have difficulty adapting. The use of CSE makes understanding what goes right, and what occasionally does not, a routine learning process that can improve the ability to adapt.

Summary

We need to learn what people actually do in health care teams and how to design work processes and systems based on that knowledge. This calls for an approach that reveals the true nature of work as it is actually done, not as it is intended to be done. CSE serves that purpose well.

Early data collection and analysis activity in our BICU research have identified the network of those who care for patients, the information sources they use, and the flow of patient care activity. Continued visits are expected to deepen the understanding of interrelationships among clinicians, how they address and resolve conflicts such as different agendas, the information sources and their use, and cognitive activities for each of the clinical specialties and roles. Results from this first year of study will be used to develop requirements for decisions that clinicians make. Requirements and use cases will provide the basis for a prototype to be developed and evaluated in the project's second and third years.

The well-designed valid cognitive artifact that results from our use of CSE is intended to support individual and team cognitive work, which is expected to improve the reliability and efficiency of clinical care for patients.

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Support for ICU Resilience

Using Cognitive Systems Engineering to Build Adaptive Capacity

Christopher Nemeth, PhD, Shilo Anders, PhD, Anna Grome, Beth Crandall, Cynthia Dominguez, PhD
Cognitive Solutions Division
Applied Research Associates, Inc.
Fairborn, OH
cnemeth@ara.com

LTC Jeremy C. Pamplin, MD, LTC Elizabeth Mann-Salinas, Maria Serio-Melvin
Army Institute for Surgical Research (AISR)
San Antonio, TX
jeremy.c.pamplin.mil@mail.mil

Abstract*—Sensitivity to patient needs makes clinicians the primary source of adaptive capacity, or *resilience*, in the intensive care unit (ICU). Work setting complexities and contingencies make cognitive work in this setting particularly challenging. A IT-based system to support individual and team decisions and communication would increase clinicians' capacity to adapt. We report on a 3-year project now underway to develop such a system. During the first year, our research team used Cognitive Systems Engineering (CSE) methods to reveal characteristics of the work setting, goals, barriers, and individual and team initiatives to overcome barriers. Our data analyses identified requirements for the IT system that were embodied in use cases, as well as in first draft prototypes of the system architecture and user interface. Our team is currently evaluating the interface prototype for face validity and refining details prior to starting programming. Interactive prototypes will be evaluated against criteria identified in field research to ensure validity. The resulting system is expected to improve staff decision making ability and communications with an expected improvement in unit adaptability. Shared decisions based on better information about procedures and resources are expected to improve staff efficiency and decrease missteps, lapses, delays in care, and the occurrence of morbidities including wrong medication/dose, infections, and unanticipated emergencies such as cardiac arrest.

***Keywords*—cognition, decision support, communication, healthcare**

Introduction

The U.S. Department of Defense maintains one of the largest healthcare networks in the world. It provides in-patient and out-patient care for the active military, their families, reserve forces, veterans, and local civilians through various military healthcare centers. Caring for patients who are admitted to Intensive Care Units (ICUs) presents healthcare teams with unique challenges that stem from patients' fragile condition and the complex combination of life-threatening injuries and illnesses they face.

This work is supported by the US Army Medical Research and Materiel Command under Contract No.W81XWH-12-C-0126. The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation. In the conduct of research where humans are the subjects, the investigator(s) adhered to the policies regarding the protection of human subjects as prescribed by Code of Federal Regulations (CFR) Title 45, Volume 1, Part 46; Title 32, Chapter 1, Part 219; and Title 21, Chapter 1, Part 50 (Protection of Human Subjects).

Care for ICU patients necessarily depends on collaboration by staff members from a number of healthcare disciplines and relies on clinician decision making and related activities, which is termed *cognitive work*. Care providers among multiple professions must work together to make effective decisions, develop treatment plans, assess patient progress, and refine care management over time. However, their decisions are only as good as the information that is available and evident when the decisions are made. For this reason, the Institute of Medicine [1] has recommended improving access to accurate, timely information, and making relevant information available at the point of patient care.

Computer systems and knowledge resources are available to support cognitive work, but gaps among these resources and among care providers cause difficulties in healthcare delivery. As a result, critical information that is needed to make decisions is difficult to obtain, is often unavailable when it is needed most, and is difficult to share.

The Cooperative Communication System

Healthcare providers and related sources of information including information systems, equipment displays and more comprise a joint cognitive system [2] that is used to manage care activities. Our research team is developing a Cooperative Communication System (CCS) that will serve as part of the joint cognitive system in a 16-bed military tertiary care Burn ICU (BICU). The CCS is expected to enable the healthcare team to remain connected to an individual patient, patient information, and to each other across time and location as the team delivers care. It will keep providers informed of a patient's status, and of other healthcare providers' patient care activities, enable the staff to understand goals, objectives and tasks related to each patient, and to reconcile differing points of view. The decision support that the CCS provides will make it possible for clinicians to make more accurate and timely diagnoses, order more timely and appropriate tests, and make better plans so that patients receive better care. Use of the CCS is expected to improve patient outcomes by improving the availability of information, and the synchronization of care among BICU team members.

The CCS project is organized in three phases. Phase 1 collected and analyzed data to understand the cognitive work and barriers to effective patient care. Results were used to develop CCS system design requirements. Phases 2 and 3 will develop a prototype CCS system and a test bed based on the BICU clinical environment that will be used to evaluate the CCS system with clinicians.

METHODS

Descriptions of clinical cognitive activities rely on understanding how individuals and groups perform them in an actual ("field") work setting. Field research requires immersion to enable the researcher to observe actual work practice and gain insight from deep, repeated inquiries [3].

A. Human Subject Research Approval

Before any data were collected, the research team obtained approval for human subject research from the funder and research site Institutional Review Board. A total of 151 staff members consented to participate.

B. Cognitive Systems Engineering

Understanding any work domain and the forces that shape it requires methods that are suited to its study. The project team is using a Cognitive Systems Engineering (CSE) [4, 5] mixed methods research approach, which is particularly well-suited to study cognitive activity in field settings such as the Burn ICU. Cognitive Systems Engineering is the process of learning about behavior and cognition as humans confront complexity in their work settings, and providing tools to support their behavior. The CSE approach is used to translate knowledge about human cognitive performance such as what is needed to attract attention to unexpected data into principles and techniques to develop solutions including human-computer interface design. [6]

Fig. 1 illustrates five phases in the approach and how the activities in each map to phases of this project.

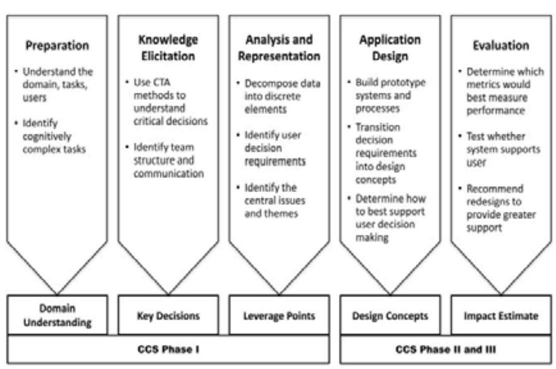

Fig 1. Five phases of Cognitive Systems Engineering. Adapted from [7]

As "systems engineering," the CSE approach includes all agents that can act in the work setting, such as a Burn ICU that is being studied. As Fig. 1 shows, CSE phases span data collection, data analysis, and solution development. Integration of these five phases ensures that the solution the process produces is grounded in worker and work setting data. The ability to identify each element among workers, work setting, and tools can also help designers to anticipate shifts and unintended consequences that occur when new information technology (IT) such as the CCS is introduced [8].

During the first year, the project team collected data over 10 months in four week-long visits to the Burn ICU. During each visit, the team conducted formal interviews, observed and shadowed clinicians, and documented artifacts such as paper forms, information systems, and displays that the staff uses to help them accomplish their work. The team's research nurse helped to collect data when the team was not at the research site. Following each site visit, team members met to analyze the data over multi-day analysis sessions. Data analysis involved several iterative steps. The team reviewed and discussed data multiple times to understand it thoroughly, identify gaps, reduce data, and synthesize it into findings.

The team started with structured and systematic passes through the data to detect patterns, or themes, which described both the ICU work setting and clinician cognitive work. The team used the themes they had developed during the team working sessions to code interview transcripts and observation notes that identified relevant portions for each theme. After data coding, each research team member was assigned a subset of the coded data excerpts to review and interpret. The team held another two-day working session to synthesize and integrate findings. Following the synthesis, the team created initial requirements for CCS according to barriers clinicians face and what the CCS system could do to help clinicians to overcome them. The team then presented the challenges/barriers and initial requirements to two physicians and three nurses on the unit to get their initial appraisal of the findings' face validity.

The analysis provided the means to identify Burn ICU clinical team cognitive work requirements. The team also closely reviewed the forms and documents that the Burn ICU clinical teams use to understand the kinds of information they seek, use, and share with one another. They developed models of the BICU work domain and clinician decision-making and patient care through this process that described the unit's information content and flow that the prototype CCS system will help to manage.

FINDINGS

The project team identified 20 key challenges and barriers to cognitive work on the BICU, then translated them into concise problem statements and information system requirements. They developed representations to describe the BICU environment and key resources that clinicians use there, formulated a set of use cases to describe to developers how the system is intended to work, and developed an initial descriptive model of Burn ICU cognitive work (Fig. 2).

Fig 2. Model of cognitive work

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A. Model of Cognitive Work

Complexity can hide underlying systematic patterns in cognitive work. Fig. 2 illustrates these patterns in the BICU. Synchronization of patient care among clinicians and over time is the top level of the model. The next level down includes activities that all unit members perform: clarification, coordination, negotiation, and anticipation, followed by supporting tasks. Each task can be observed in the way that clinicians interact with each other and use information sources to minimize uncertainty. Requirements that the team developed from these tasks indicate opportunities, or leverage points, to improve synchronization.

B. Patient Care Providers

Part of the challenge in this project is to know how to bound it. To do that, the team asked "Who do you communicate with to do your work?" of 8 nurses, 5 respiratory therapists, 2 physical therapists /occupational therapists, 1 nutritionist, and 1 physician. Fig. 3 shows the resulting network that can be used

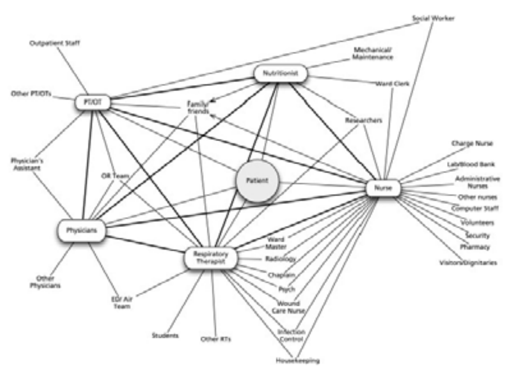

Fig 3. Care provider relationships closest to patient

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to develop the CCS interface structure. Thicker lines show that communication was mentioned by both parties, and enable the team to organize interface screens according to clinical roles. This initial network will expand as project work continues, providing the basis for interface views that are organized according to BICU work roles.

C. Information Sources

The team identified a range of information sources (shown in Fig. 4) that need to be used together to manage care and manage the ICU. Ten are computer-based, 3 are paper artifacts, and 3 are computer-based displays that produce a paper printout. Communications including cell and land line phones and email are further information sources. The set describes an inventory of information that matters to the clinicians, and each needs to be included in the CCS solution.

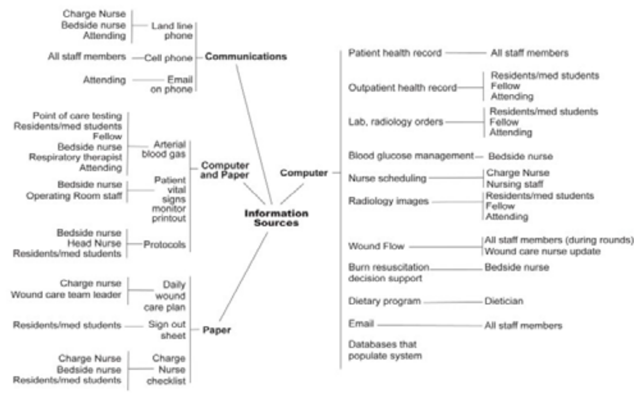

Fig 4. Information sources clinicians use on the BICU

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D. Barriers

Each of the barriers the team discovered presents an opportunity to ask how the CCS system can help to improve unit synchronization. Here are four of the 20 barriers that the team discovered:

No effective means exists to synchronize aspects of patient care.

There is a lack of awareness of activities and events that are tightly coupled.

There is no efficient way to communicate changes in patient status across clinical specialties.

Updated information such as results of laboratory cultures is available but is not accessible or visible.

E. Requirements

Using the challenges and barriers, the team created a set of problem statements and then developed concise statements of system requirements for each. The first barrier provides an example:

No effective means to synchronize and adapt different aspects of patient care over the course of a shift, across caregiver team.

The requirement states how the CCS solution can help to overcome the barrier:

System shall provide access to a plan of patient care, visible to all care givers responsible for that patient that includes:

Current patient status and top-level assessment;

Goals and priorities for those goals;

Changes/updates, such as indication that plan is being updated when one caregiver is working on it;

Schedule of activities and any changes, timeline;

Orders and their status;

Identity and contact information for patient's care team

The requirement starts to describe the CCS interface's content and operation. The complete set of requirements, which is directly related through the analyses to the original data, can be used to create a series of use case scenarios.

F. Use Case

The first paragraph of a use case for the above requirement describes how each of these features (shown in bold type) would serve clinician needs.

> *At 0630, a bedside nurse has started his preparation for the day* ***shift*** *by reviewing information on the patient he is responsible for. Opening CCS, he can see a* ***roster of patients on the unit,*** *chooses his patient's* ***"at-a-glance" view*** *that shows* ***recent vital signs, current orders, medications, care plan,*** *and* ***notes from the night shift.*** *He checks the patient's standing* ***care plan*** *and* ***treatment goals*** *(from the electronic healthcare record), and* ***reviews orders*** *(from the laboratory test database) that are pending as well as the day's* ***care activities that the Wound Care team, Respiratory Therapists, and Physical Therapists*** *have recommended and* ***what times*** *they can perform them.*

The information designer and programmers will use these requirements and use cases to develop, evaluate, and refine prototypes in Phases 2 and 3.

DISCUSSION

Methods from CSE can be used to learn the nature of work as it is actually done, and when it is done, by those who do it. This makes it possible to create effective solutions that workers recognize and readily accept. Using knowledge about a work setting such as the Burn ICU can improve workers' ability to operate in spite of significant challenges such as unexpected changes in the type, rate, and volume of care demand [9]. Insights from such studies can also help to contribute to the system's ability to adapt—to be more *resilient* [10]—when workers are confronted with unforeseen challenges.

Three characteristics that CSE can assist include: being self-aware, the ability to identify and apply resources, and the ability to adapt to surprise.

A. Self-Aware

The "cottage industry structure of the national healthcare delivery system" results in "disconnected silos of function and specialization" [11]. This disconnection among specialties is aggravated by disconnected information sources. In this BICU, for example, the electronic healthcare record is not connected to the outpatient record or the database that tracks laboratory test results. Coping with these gaps forces clinicians to invent their own "workarounds." One workaround is to read a display on one system, write needed information onto a scrap of paper, walk to another system display, then key in the information. The process not only opens the door to transcription error, but also takes away from time that could and should be spent caring for the patient.

The CCS can contribute to ICU self-awareness by bridging the many databases that are currently unconnected. The synthesis of information sources would also open the way for data mining to seek and extract meaningful patterns of information that are related to the patient, the unit, or the clinician(s).

B. Able to Identify and Apply Resources

Clinical skills, supplies, equipment, and portions of facilities are routinely assembled to perform each Burn ICU procedure. Patient condition and readiness for a procedure can change, and clinicians, equipment, or rooms can become available or unavailable. Scheduling is currently done using hard copy forms and in-person negotiation, which makes it difficult to develop and maintain an optimal plan.

The CCS can improve the ability to identify and apply resources through scheduling that supports both planning and re-planning (making changes to plans as the day progresses).

C. Able to Adapt to Surprise

We have shown in prior publications [12, 13] how healthcare organizations respond to events, particularly misadventures. With insufficient information on what actually occurs, the response attempts to isolate the cause and declare that it will not happen again. A system that can adapt to surprises and challenges can also be used to learn about its response. The use of CSE makes understanding what goes right, and what occasionally does not, a routine learning process that can improve the ability to adapt.

Data mining being developed for the CCS will make it possible to detect and illustrate trends. Understanding how a patient or group of patients fares over time can improve clinicians' ability to adapt to surprises such as unexpected changes in patient condition.

SUMMARY

Health IT has significant, pervasive effects on health care delivery, patient safety, and care quality. Methods within the of CSE approach can be used to identify patient care and work setting complexities that affect clinicians and the decisions they make. That understanding can be used to develop requirements for computer-based cognitive aids to improve individual and team decision-making and communication.

The system that the CCS project produces is expected to improve clinical decision making and communication as well as unit adaptability. Shared decisions based on better information about procedures and resources are expected to improve staff efficiency. The CCS system is eventually expected to help to decrease missteps, lapses, delays in care, and the occurrence of morbidities including wrong medication/dose, infections, and unanticipated emergencies such as cardiac arrest. As the study continues, the research team will design and develop a prototype that can also mine data for relevant information, then test and validate the prototype using criteria from the first year of research.

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Discovering Complexities in Critical Care and Their Challenges to Health IT Design

LTC Jeremy C. Pamplin, MD

And

Christopher Nemeth, PhD, CAPT USNR (Ret.)

Society of Critical Care Medicine Annual Congress

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10 January 2013

Disclaimer

"The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense."

Conflicts of interest: None

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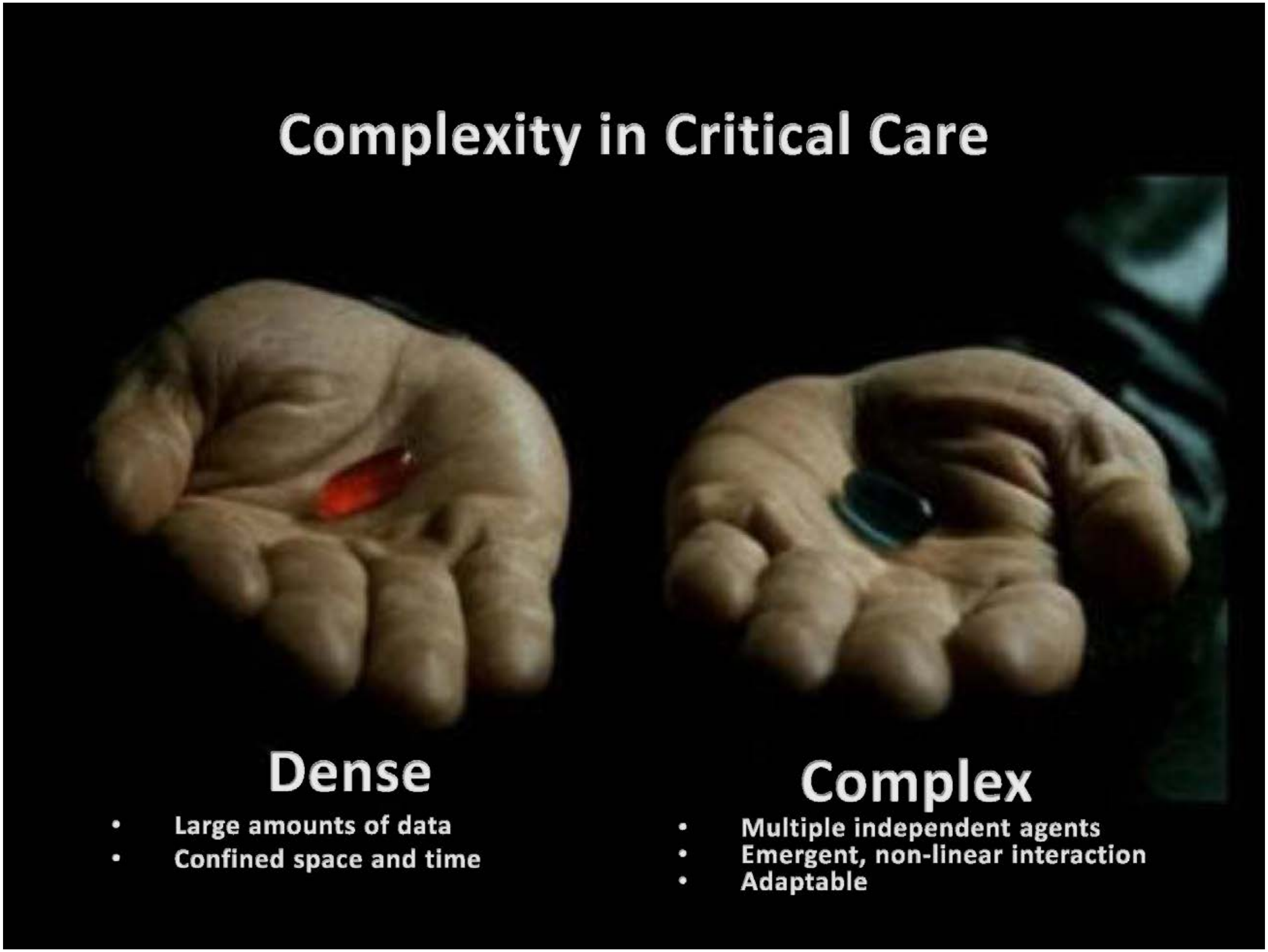
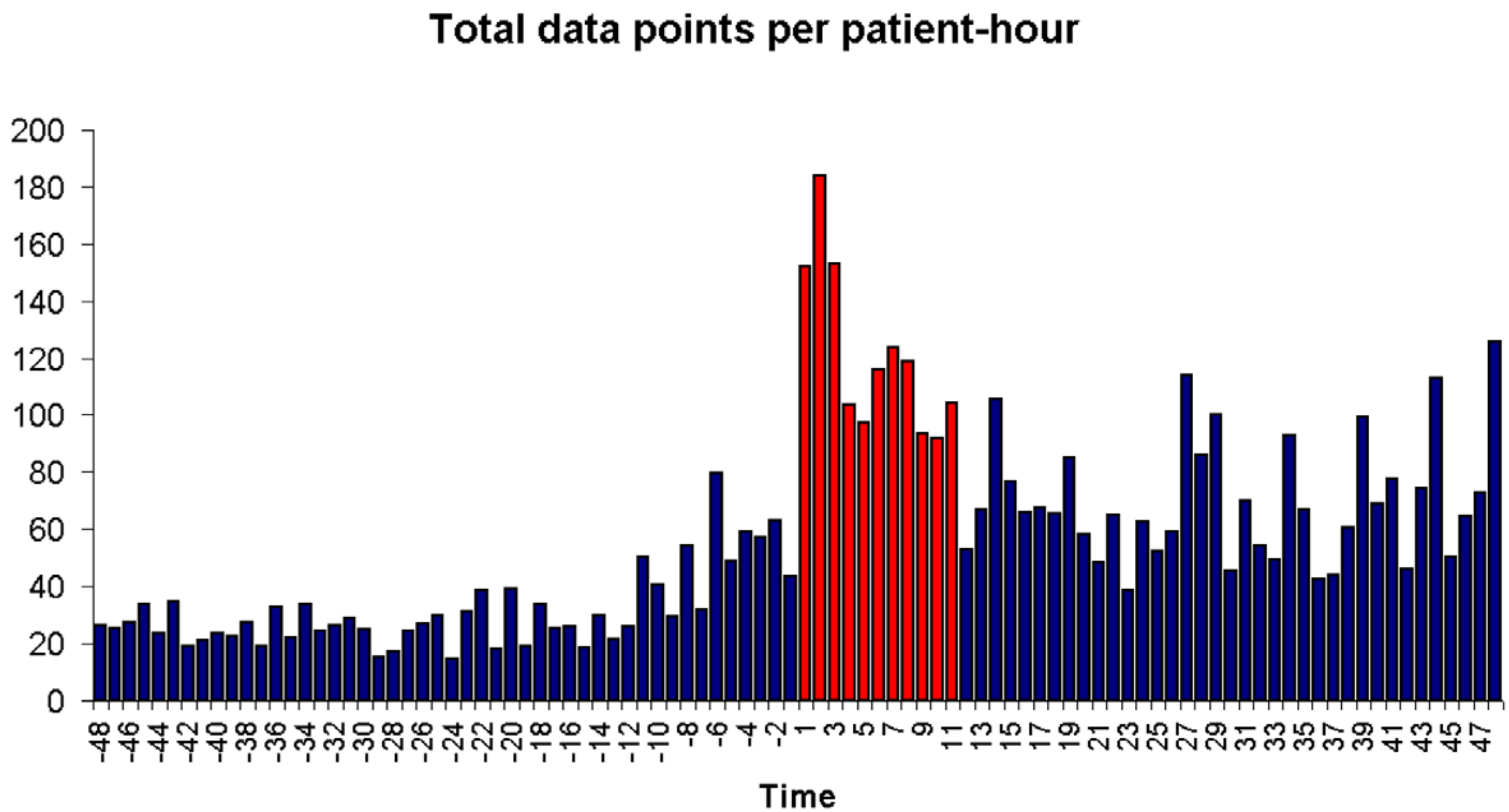
2

Background – The problem

- In 2009 we were frustrated with our electronic health record and began seeking answers as to why
- At that time, we discovered there was little apparent science into how EHRs were designed
- More importantly, our clinicians still longed for the large, paper-based flow-sheets of ICUs since past…. a foolish dream?
- So, we asked, what should we display on an electronic representation of the data we once found so easily in an paper flow sheet?


Complexity in Critical Care
Dense
• Large amounts of data
• Confined space and time
Complex
• Multiple independent agents
• Emergent, non-linear interaction
• Adaptable

Data volume before and During ICU



*Microbiology, labs, medications, chest X-ray, Nurses flowsheet, Clinical notes (history and impression/plan) – **Vitals excluded***

* Slide courtesy of Dr. Vitaly Hersavich, Mayo Clinic

5

Where's the patient?

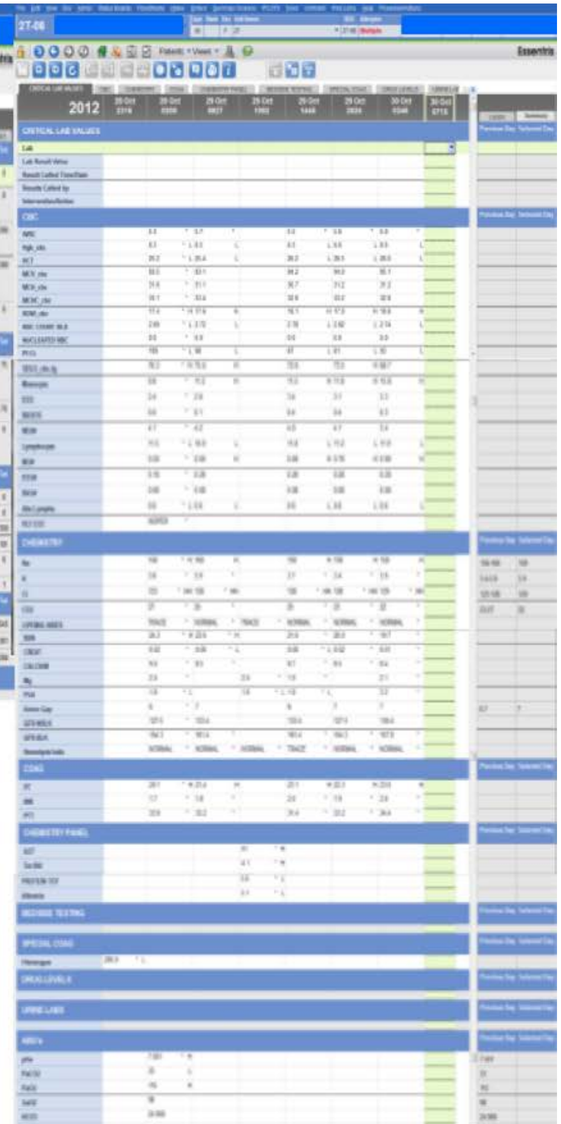
6

Who’s in Charge? When?

7

Vital Signs

In’s & Out’s

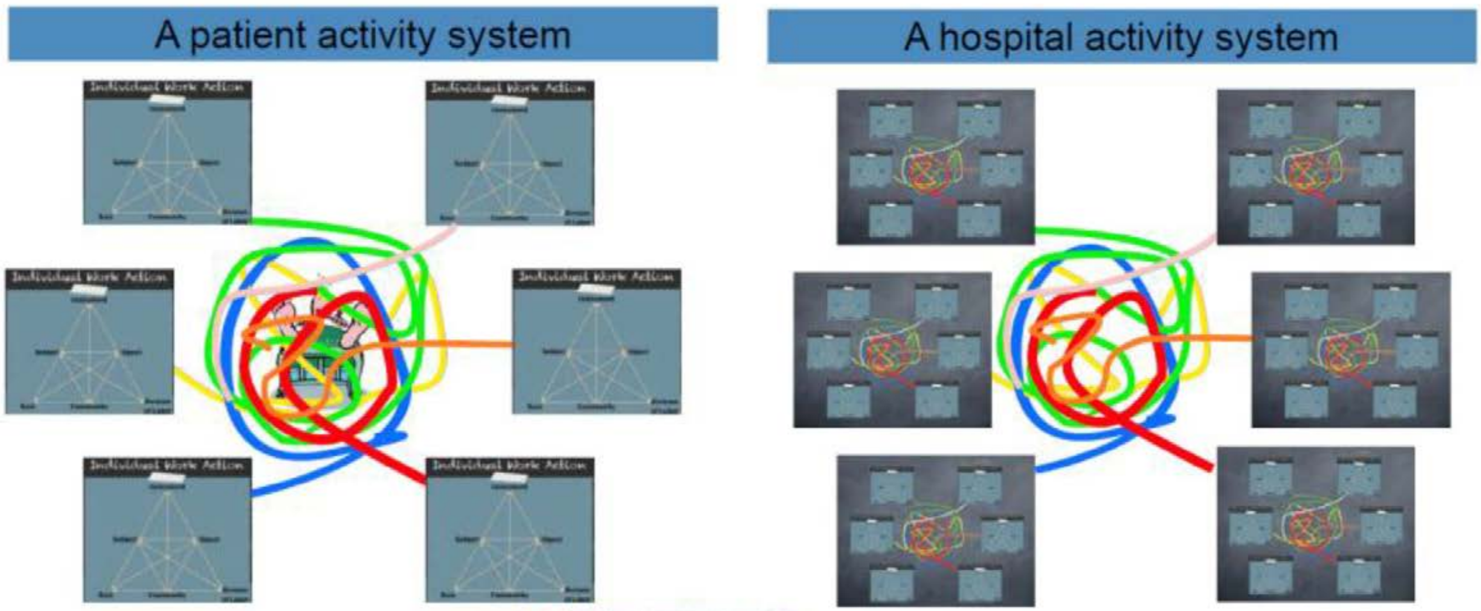


Labs

At least 8 different computer screens!

** Not shown: Radiology, TEG, CHCS labs, outpatient record, “foreign” records, images, etc.

The system of care



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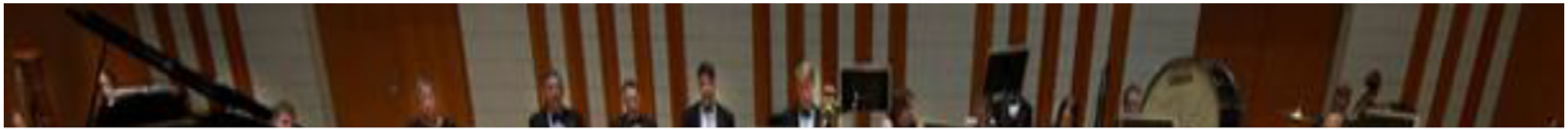


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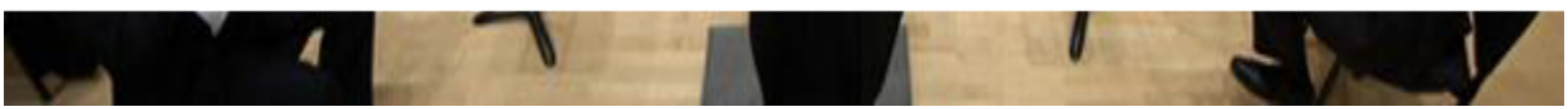
16



Objectives

Overall Activity Objectives

To improve care by supporting clinical decision-making by identifying design requirements for computerized cognitive aides and communication tools.

Identified Problem

Traditional scientific methods in medicine do not “unpack” the healthcare system well.

This results in:

False assumptions

Limited understanding of the work domain

Cognitive systems engineering has demonstrated effectiveness in understanding other clinical domains such as the operating room, emergency department, and the pediatric ICU*

*Nemeth et al. IEEE Transactions on Systems, Man, and Cybernetics, Part A. (2003) vol. 34 pp. 726-735
*Nemeth, et al. (2003). A Study of Pediatric Intensive Care Unit Technical Work. The University of Chicago.

WHAT IS CSE?

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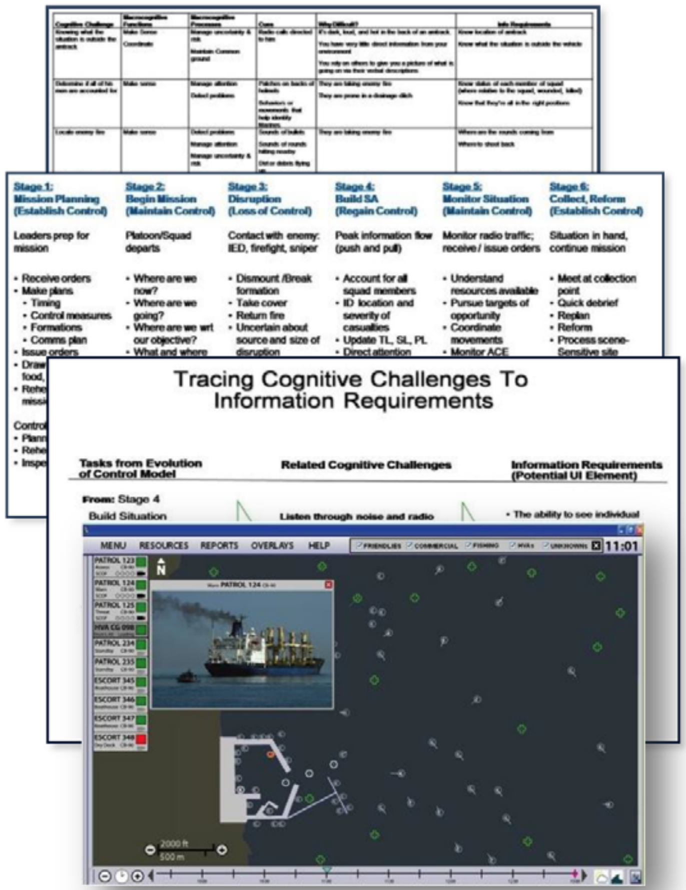
Cognitive Systems Engineering Process Molds Result

Understanding clinician cognitive work in response to challenges molds requirements for solutions such as computer-based cognitive aids



Field data collection leads to

↓

Descriptive cognitive models, to

↓

Decision and information requirements, to

↓

Prototypes to be evaluated and optimized

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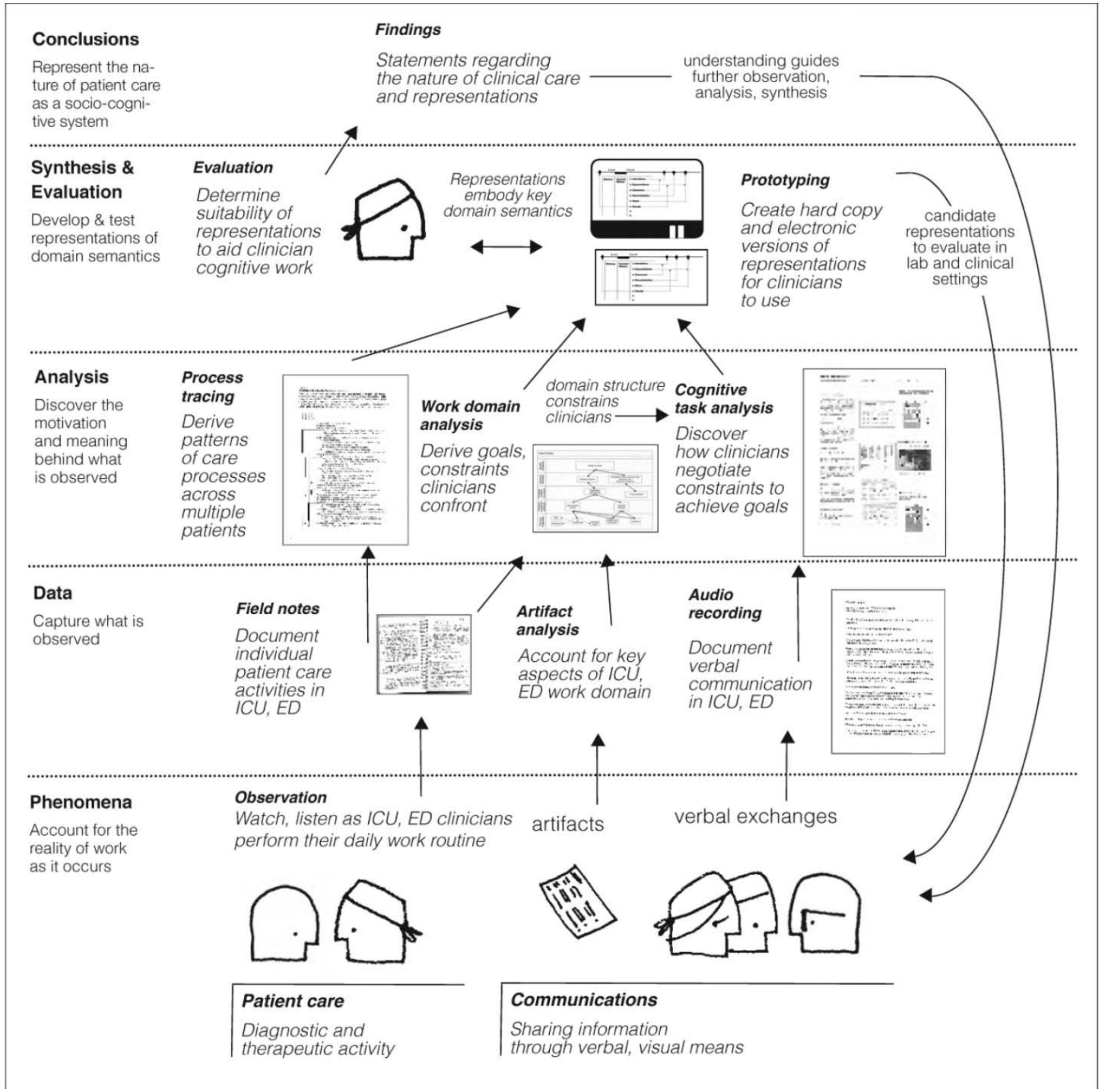
Research Design



Research Site

- Study conducted according to USAMRAA IRB human subject research requirements
- 16 Bed Burn ICU in tertiary care medical center. Population averages 8 patients, but as high as 16.
- Severe affliction from chemical, mechanical or electrical burns, or burn-like afflictions (e.g., toxic epidermal necrolysis (TENS)).
- Length of stay from days to months.
- Nearby units support BICU, including step down unit, burn OR, and outpatient clinic.

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Preliminary Results

Clearly identified:

- Goals, and barriers to goals
- Complex network of relationships clinicians maintain and negotiate to provide patient care.
- Information sources on which clinicians rely
- Clinician work processes, including communication

- Insights into work domain, operator issues. For example:

  "The bedside nurse is the central figure of an ICU patient's clinician network."

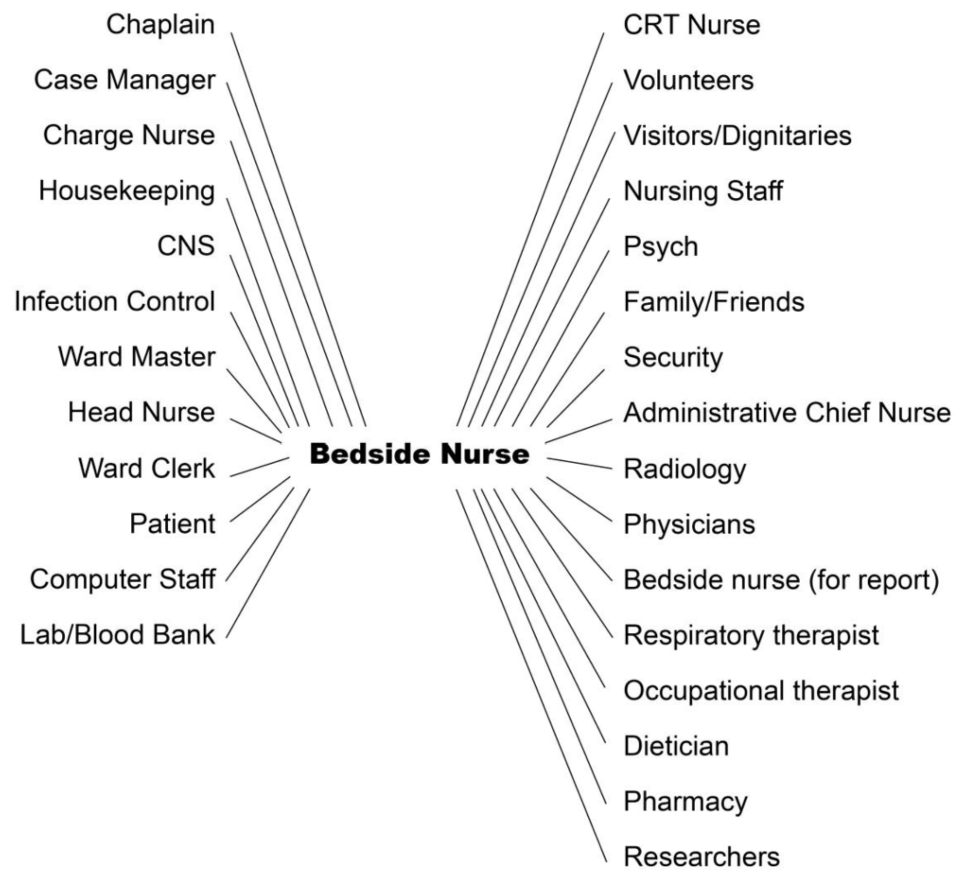
Pop Quiz!

Q. How many work relationships does the BICU bedside nurse maintain?

Preliminary Results

Q. Number of BICU bedside nurse work relationships?

A. 31+



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Preliminary Results

- The bedside nurse is informally responsible for a host of other activities.
- An important example is reconciling conflicts among:
  - Information sources
  - Protocols/guidelines
  - Unit policies
  - Physician orders
  - Consultant recommendations
  - Care priorities among many daily needs
  - Patient and family preferences and requests

Example Data

Quotes from nurse interviews:

“Why can’t the doctors make up their minds on what they want me to do?” (Nurse)

“Doctor _______ [surgeon] wants this type of dressing, but the wound care specialists want us to use 5% SMS.” (Nurse)

“The intern told me to give the patient PEG, but he’s already on PO narcan and we just started feeding him.” (Nurse)

Example Coded Data-Theme

Quotes from nurse interviews:	*Barrier*
"Why can't the doctors **make up their minds** on what they want me to do?" (**Nurse**)	**Conflict** between doctors
"Doctor _______ [surgeon] wants this type of dressing, **but** the **wound care specialists** want us to use 5% SMS." (**Nurse**)	**Conflict** between doctor and Wound Care specialist
"The **intern** told **me** to give the patient PEG, **but** he's already on PO narcan and we just started feeding him." (**Nurse**)	**Conflict** between junior physician and nurse

Example Theme

Quotes from nurse interviews:	*Barrier → Theme*
"Why can't the doctors **make up their minds** on what they want me to do?" (**Nurse**)	**Conflict** between doctors → **Nurse reconciles**
"Doctor ________ [surgeon] wants this type of dressing, **but** the **wound care specialists** want us to use 5% SMS." (**Nurse**)	**Conflict** between doctor and Wound Care specialist → **Nurse reconciles**
"The **intern** told **me** to give the patient PEG, **but** he's already on PO narcan and we just started feeding him." (**Nurse**)	Conflict between junior physician and nurse → **Nurse reconciles**

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Implications

New understandings for the BICU staff, development team.

- The bedside nurse:
  - Is central to ICU patient care
  - Has unsupported & unrecognized responsibilities that detract from direct patient care

Implications

- These findings reveal
  - The necessary flexibility of the nurse
  - Delays in decisions and care caused by missing information, unresolved conflicts, unanswered questions
  - The bedside nurse is ***the*** safety-net for the patient and the unit.
- Computer-based cognitive aids need to support these aspects of a nurses work in addition to their direct patient care activities.

Next Steps

- Derive quantitative evaluation criteria to compare clinical support tools
- Complete decision and information requirements
- Design, develop a prototype compatible with DoD IT requirements
- Test and validate the prototype in concert with other IT solutions that are currently in use
- Field in a clinical setting

We welcome your questions and comments

LTC Jeremy Pamplin, MD
jeremy.c.pamplin.mil@mail.mil

Christopher Nemeth, PhD
cnemeth@ara.com

Our thanks to
Dr. Shilo Anders, Anna Grome, Beth Crandall, Jeff Brown, Dianne Hancock, Greg Rule, Nicole Caldwell
for their instrumental support of this project, as well
all of the clinicians who patiently participated in this research.

True or False

- The following statement is taken from the 2012 National Academies of Science report on Healthcare IT.

"Medical and diagnostic devices have produced a therapeutic revolution, but in doing so they have also become more complex and less easily understood by those who use them. When well designed, well made, and properly used they support and lengthen life. If poorly designed, poorly made, and improperly used they can threaten and impair it."

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False

- Where is it from?
  - President Gerald Ford, signing statement for Medical Device Amendments, May 28, 1976.

- We’ve been with this issue for over 45 years, and it is still significant.

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Emergent Themes 1

Theme	Definition	Questions
Rework	Bridging and workaround strategies to link systems that don't talk to each other.	
Information continuity	ABD does/doesn't connect to Essentris. Volume 2 needs to be created for long-term Pt.	Transcriptions FM ___WMSNi to Essentris; Values too high for entry.
Negotiation	Among individuals, specialities, levels of expertise dynamic requiring negotiation hourly/by shift/daily.	What? How well? What's fair game? Who? What is off limits? Tacit?
Scheduling	Planning, replanning among, across patients and specialties.	
Anticipation	Patient status, needs and how to meet them. Preparation and participation in events.	

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Emergent Themes 2

Coordination	Collaboration requires expression of expectations, prioritization, agreement, recruitment/transfers.	Who needs to know? When? How far ahead? What is information appropriate to each role?
Clarification	Inquiry, sensemaking, common grounding to reach threshold of confidence to accept responsibility drives down level of uncertainty.	Who do I/we know? Do I/we trust it? Implications? What else do we need to know? Do about it?
Resources	Access. Availability. Permission. Provision. Preparation. Authority. Certification. Use ["Technical Work"]	What's available? Who controls it? Can I get it for my patient? When? What's difference between presumed vs. actual resources?
Tasking	Assignment of ICU staff to best match patient needs. Individual abilities/experience. Team needs.	Who is best match and why? What unofficial information matters here?

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Emergent Themes 3

Cross Check	Identify/confirm/correct information problem detection. Does it create drag?	Is there a problem? Does this align with my expectations? How much time does it require?
Tracking	Account for what needs to be done, whether it has been completed, what remains to be done.	Who tracks? How? Do new items modify or change the set? Priorities?
Gaps	Ability to see "what isn't there"	Why isn't this here? What's going on here? Why isn't what I'm expecting to be here present?

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Barriers/Challenges

Theme	Definition
Limited orientation	Of residents and float RNs. RN's fill gap-takes time from patient care
Lags in info: meds, labs, & blood	Rely on verbal orders: "on sly" not fully socialized/shared; consistent care delays
Bedside nurse reconciles conflicts	Technology protocol, guidelines, policy, regs vs. patient care needs (e.g. Mixing ketamine, consult note conflicts)
Procedural Drag	Transcription. Work arounds due to system organizational gaps
Reliance on memory as failure marker	Technology fails to support needed work. E.g. afternoon rounds not fed forward to next day
Story of the patient/big picture lost	Trend info, understanding lost/degraded over long term of care, no synthesis
Reliance on verbal exchanges	Info flow porous, brittle, not shared, not reliable; e.g. Acinetobacter treatment event; patient admission

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Barriers/Challenges 2

Authority gradient	Encourages passivity WRT concerns; impediment to sharing
Common grounding accuracy	Under specification, confirmation, verification, clarification; decay in treatment, charge nurse may/may not address at team level
Action/Who has the CON?	Specialties, but no accountability on team to assure results
Timing	Lack of synchrony, stal info; e.g. when procedure was performed.
Salience	Homogenous info, most relevant info, hard to find; stat orders not evident
Usability/access/usefulness	Software access, requisite operator knowledge, incorrect entry (e.g. wound flow)
Organizational issues=drag	"green box" compliance

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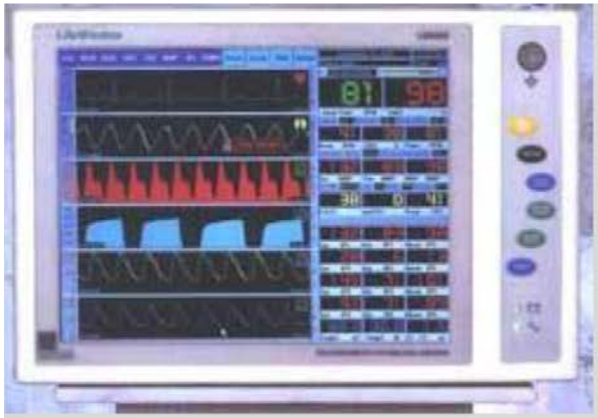
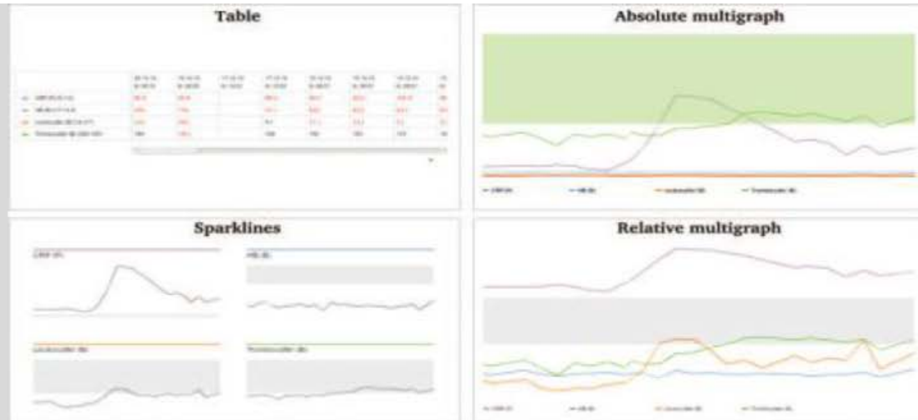


Information: data in context



Knowledge: Contextual information that gives meaning (trends, information in context)

Path to achieving an electronic system that better supports patient care?

Wisdom: Applying knowledge to new situations and knowing what is to come

Understanding

Differential Diagnosis

Treatment Options

Diagnostic Algorithms

J Am Med Inform Assoc 2012;0:1–7
Crit Care Med 2011; 39:1626–1634

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Poster # 115

Discovery of Burn ICU Critical Care Complexities and their Implications for Health IT Design.

Christopher Nemeth, PhD[1], Shilo Anders, PhD[1], Jeffrey Brown[1], Beth Crandall[1], Anna Grome[1],
Kevin Chung, MD, FCCM[2], Elizabeth Mann-Salinas, PhD[2], Jeremy Pamplin, MD[3]
1. Applied Research Associates, Inc., San Antonio, TX; 2. United States Army Institute of Surgical Research, Fort Sam Houston, TX; 3. San Antonio Military Medical Center, San Antonio, TX

Introduction

- The ICU work domain is complex and information is dense
  - Multiple independent actors interacting in emergent, non-linear relationships
  - Adaptable and resilient
  - Difficult to "unpack" and to understand
- Health IT has evolved to replace paper charting
  - Vendor-driven
  - Science behind its structure and presentation is limited, at best
  - Introduces potential safety risks and burdens to clinical work
- The clinical burden
  - Information too often missing, time delayed, hidden, or erroneous
  - Multiple, unconnected systems, often with multiple logins (EHR documentation, radiology, coding/billing, inpatient/outpatient, etc.)
  - Multiple screens of data, with limited/no salience (presenting most important data)
- What should a display look like? How should it behave?
- What activity(ies) should a computer-based decision support system assist?

Hypothesis

We can describe the Burn ICU (BICU) as a work domain and account for cognitive activities to identify design requirements for decision support and communication tools using Cognitive Systems Engineering (CSE) methods.

Objectives

To improve care by supporting clinical decision-making by identifying design requirements for computer-based decision support and communication tools.

Methods

- This project is divided into three phases:
  - Phase I: Foundation research
  - Phase II: Prototype development
  - Phase III: Prototype assessment
- Phase I
  - Conducted in a 16 bed burn ICU in a 450 bed tertiary care, military, academic medical center
  - Five one-week data collection visits, each followed by data analysis sessions.
  - Each visit includes:
    1) Direct observation of clinical teams providing patient care. Probe questions enable researchers to request background and clarifying information situated in context to better understand motivations, information use, and decision making;
    2) Structured interviews elicit knowledge from clinicians about their background, perspectives, work activity, information sources, and challenges they face;
    3) Collection of computer-based and hard copy artifacts that clinicians use in their work. These include sign-out sheets, personal notes, status boards, and equipment displays, among others.
- Through data analysis, we develop descriptive models of the BICU work domain and features of clinician decision-making and patient care. These models describe the content and flow of information that the project's prototype decision support and communication system will help to manage.

Preliminary Results

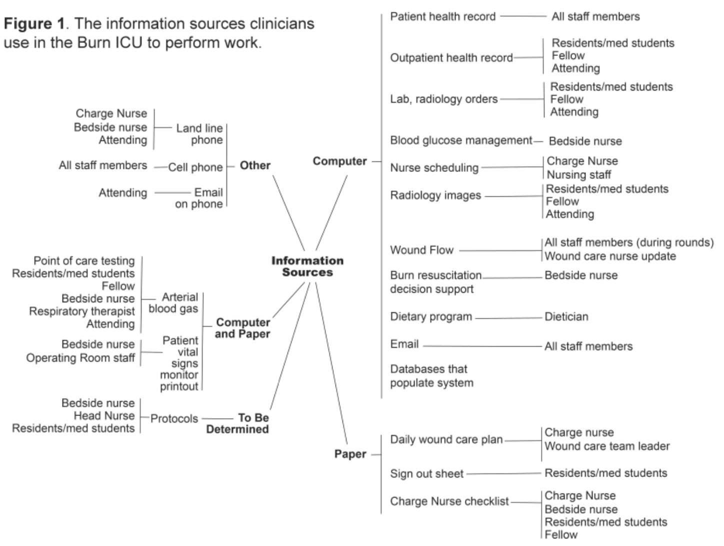
- Preliminary results have identified the key information sources that clinicians access to make decisions.
- We broadly categorized them in five groups, as Figure 1 shows:

1. **Computer Based** (e.g. inpatient and outpatient electronic health records, back end databases) that include information on:
   - Laboratory
   - Radiology
   - Blood glucose management
   - Wound care management
   - Nutrition management
   - Scheduling
2. **Computer & Paper Based** (e.g. arterial blood gas results, printed vital signs from monitors)
3. **Paper Based** (e.g. sign-out sheets, checklists, wound care plans)
4. **Other** (e.g. land lines and cell phones, pagers, text messages, e-mail)
5. **Unclassified** (e.g. protocols)

Key Points

- Clinicians use numerous formal and informal information sources during daily patient care.
- Computerized cognitive aids intended to support clinician work need to account for and/or access these information sources if they are to enhance performance.

Figure 1. The information sources clinicians use in the Burn ICU to perform work.



Discussion

- Improving healthcare IT, so that it supports patient care necessitates going beyond surface descriptions (phenotypes) of work domains to the underlying patterns (genotypes) of systemic factors
- CSE methodologies produce a deep description of the work domain studied
- Through observation, interview, and artifact analysis, we demonstrate that Burn ICU clinicians access numerous computer, paper, computer and paper, and "other" information systems.
- The design of computerized cognitive aides (e.g. dashboards, displays, communication systems) must account for these information sources.
- Failure to account for these information sources may introduce risk to an IT system causing potential patient safety concerns (e.g. delays, misses, lapses, failures in care delivery, etc.), and/or clinician frustration, workarounds, and and avoidance.

Limitations

- Single center/single unit
- Discrete observation periods

Conclusion

Understanding the sources of information and who uses them will facilitate development of IT prototypes that better support clinicians and teams in their daily cognitive work to improve their reliability, accuracy, and efficiency of patient care.

Acknowledgments

We would like to thank Dianne Hancock, Greg Rule, and Nicole Caldwell for their instrumental assistance in facilitating this project.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense..

This study was conducted under a protocol reviewed and approved by the US Army Medical Research and Materiel Command Institutional Review Board and in accordance with the approved protocol.

Funding:

- *This project is supported by a grant from the Joint Program Committee 1/ Telemedicine and Advanced Technology Research Center (W81XWH-13-2-0011).*
- *The following co-authors salaries are partially paid for by this grant as are all travel expenses related to this project: Dr. Anders, Mr. Brown, Ms. Crandall, Ms. Grome.*

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Developing a Cognitive and Communications Tool for Burn ICU Clinicians

US Army Medical Research and Materiel Command
Contract No.W81XWH-12-C-0126.

Presented by

Christopher Nemeth, PhD, CAPT USNR (Ret.), Applied Research Associates

LTC Jeremy Pamplin, MC, Army Institute for Surgical Research

To

Military Healthcare Research Symposium

Date

18 August 2014

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Research Topic Area: Bio-Informatics (1)

Supporting Warrior Care

Findings from projects/studies aimed at promoting, improving, conserving or restoring personnel mental or physical well-being through improved information management & use of emerging technologies

Photo: Dept. of the Army

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Objectives for This Session

- Become familiar with the nature of and need for human subject field research in military healthcare work settings
- Become familiar with the use of human factors methods such as Cognitive Systems Engineering to understand and support military healthcare
- Understand how human factors can help to improve military healthcare reliability, safety, efficiency, and resilience.

Photo: Dept. of the Army

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Research Site

- Burn ICU in tertiary care medical center,
- 16 beds, 2 reserved to serve as a post-anesthesia care unit (PACU), 1 dedicated to support Extracorporeal Membrane Oxygenation (ECMO).
- Other nearby units support the ICU, including a step down unit, burn operating room, and outpatient clinic.
- Population averages around 8 patients but as high as 13
- Patients have severe affliction from chemical, mechanical or electrical burns, or burn-like afflictions such as toxic epidermal necrolysis (TENS).
- Length of stay ranges from days to months.

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Research Design

- Goal is to improve care by better supporting the judgment of individuals and teams who care for patients through a cognitive aid that also assists communication.
- Three phases that are scheduled to take roughly a year apiece: foundation research, cognitive aid prototype development, and prototype assessment.

Photo: Dept. of the Army

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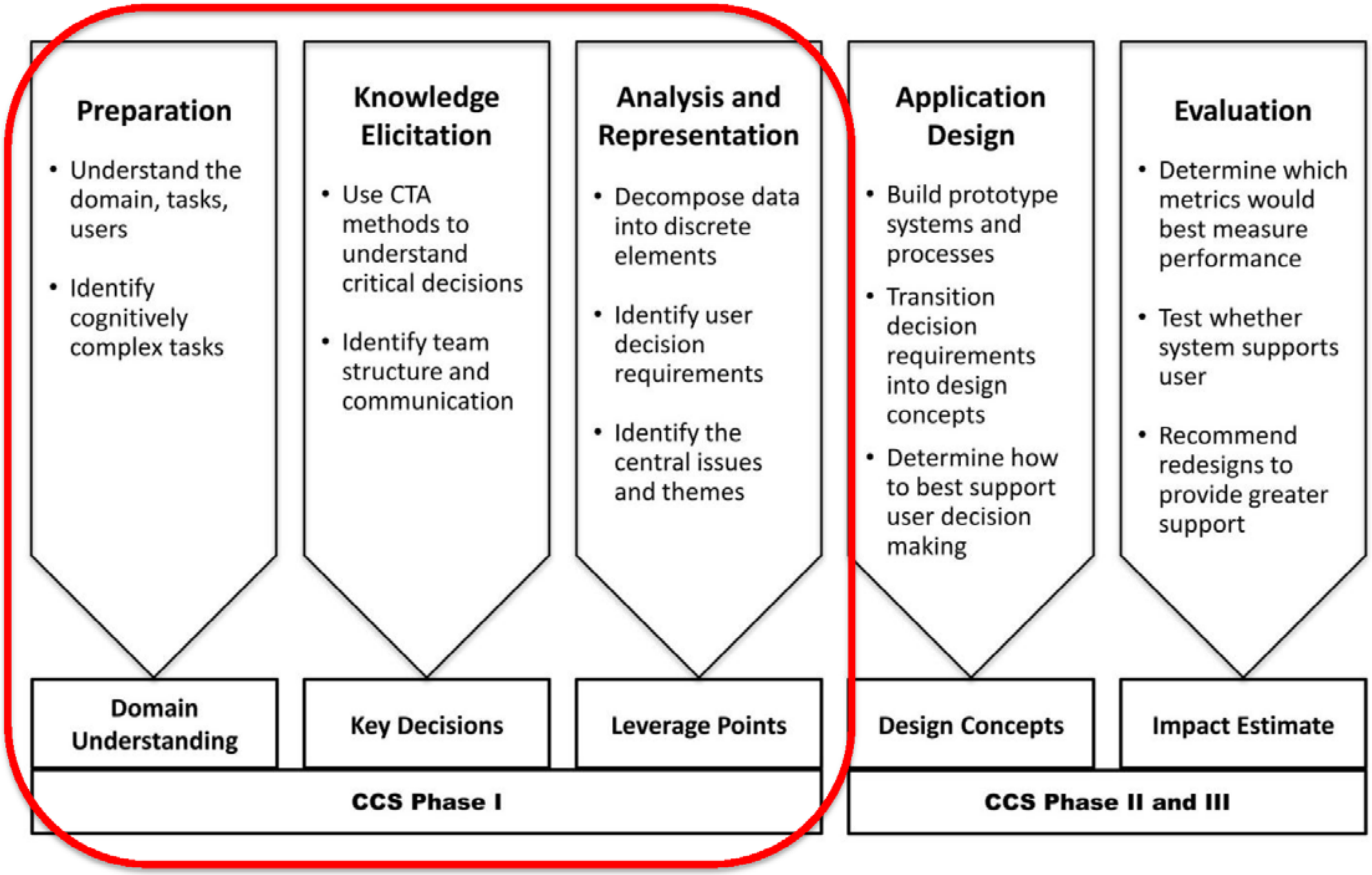
Cognitive Systems Engineering Phase 1



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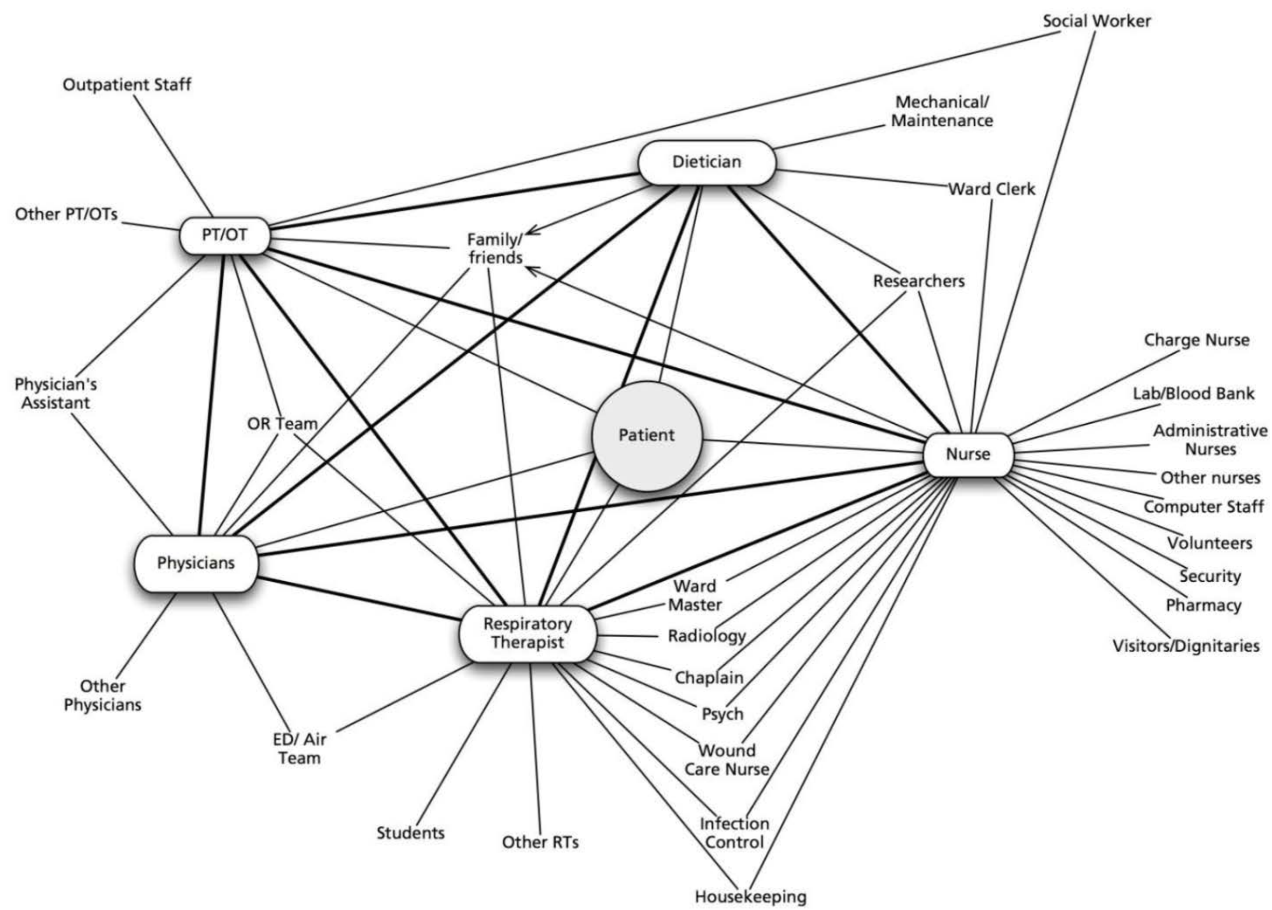
BICU Patient Team



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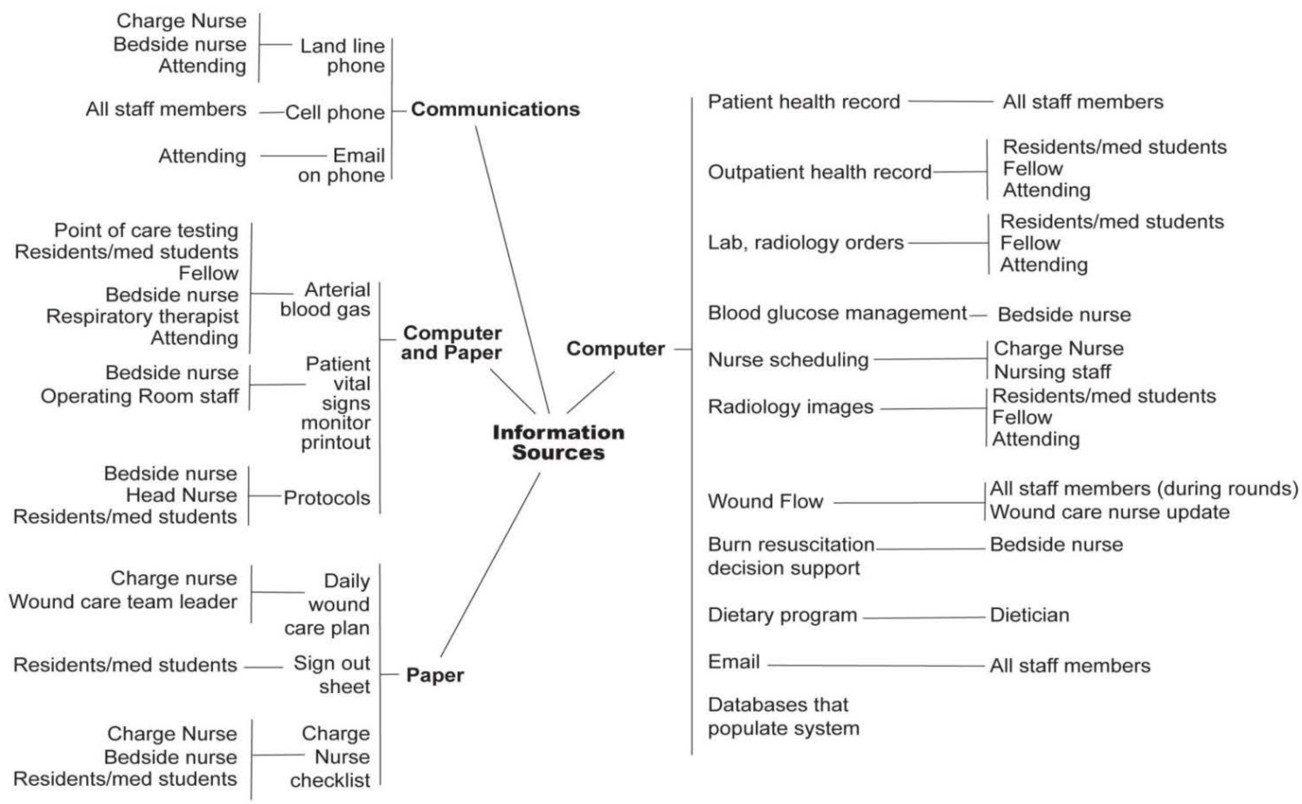
BICU Information Sources



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BICU Cognitive Model

Function Unit Members Perform	*Activities Unit Members Perform*	*Tasks Unit Members Perform*
Synchronization	**Clarification**	Reduce uncertainty Manage ambiguity Manage conflicting agendas Manage communication
	Coordination	Develop shared awareness of the Patient Get and keep common ground Manage the care plan and treatment goals Coordinate resources
	Negotiation	Identify alignment, gaps/differences (e.g., agendas) Manage conflicting agendas Manage communication
	Anticipation	Forward thinking

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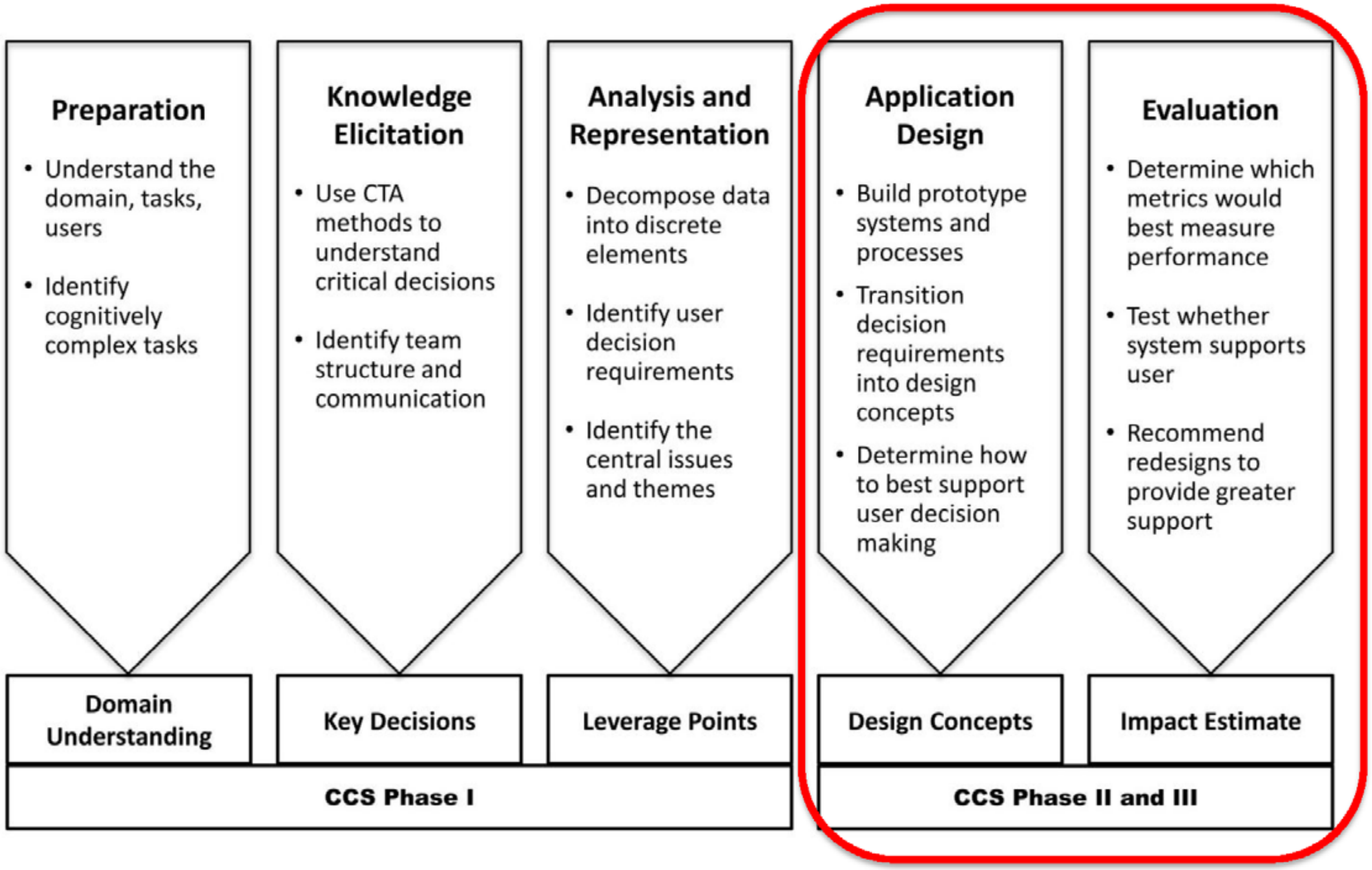
Cognitive Systems Engineering Phases Two, Three



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Patient View

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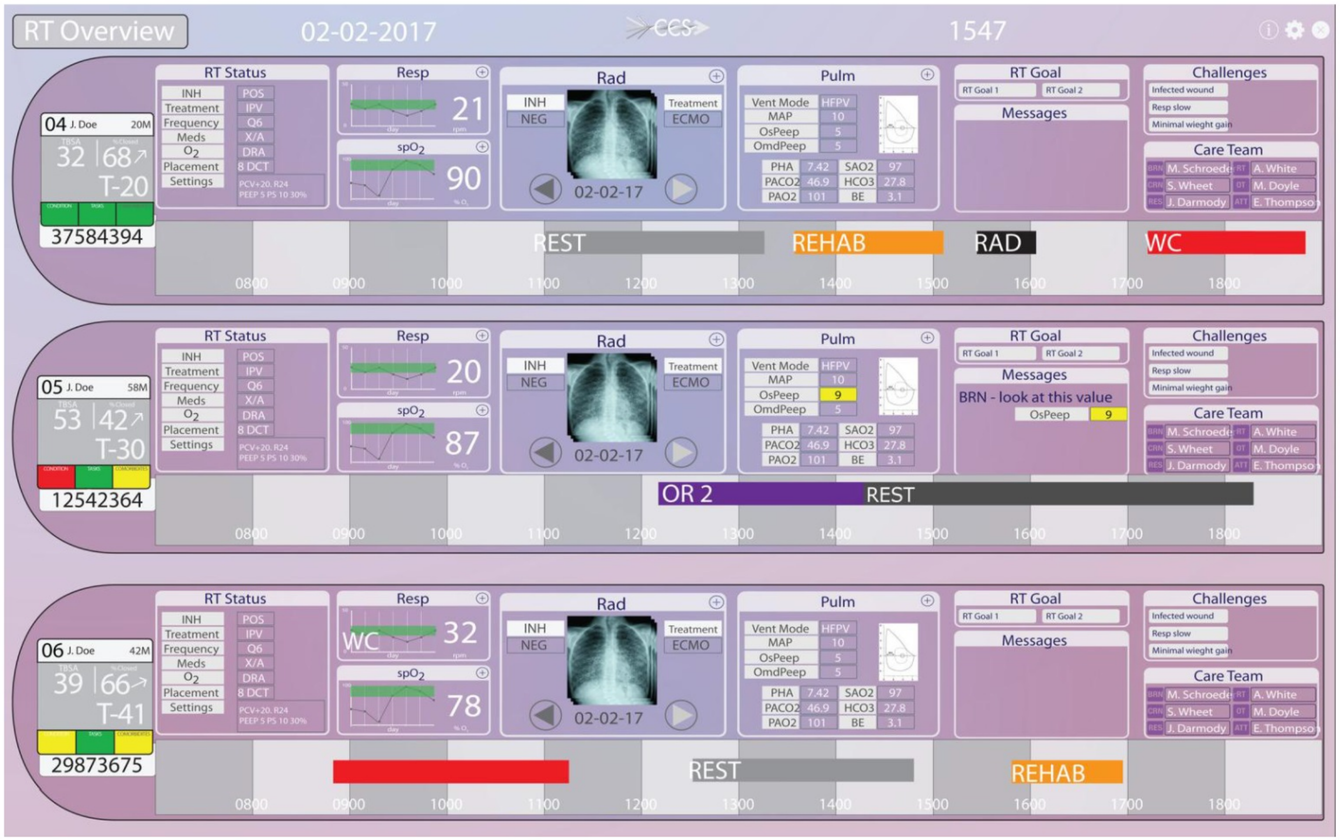
Clinician-Specific View: RT



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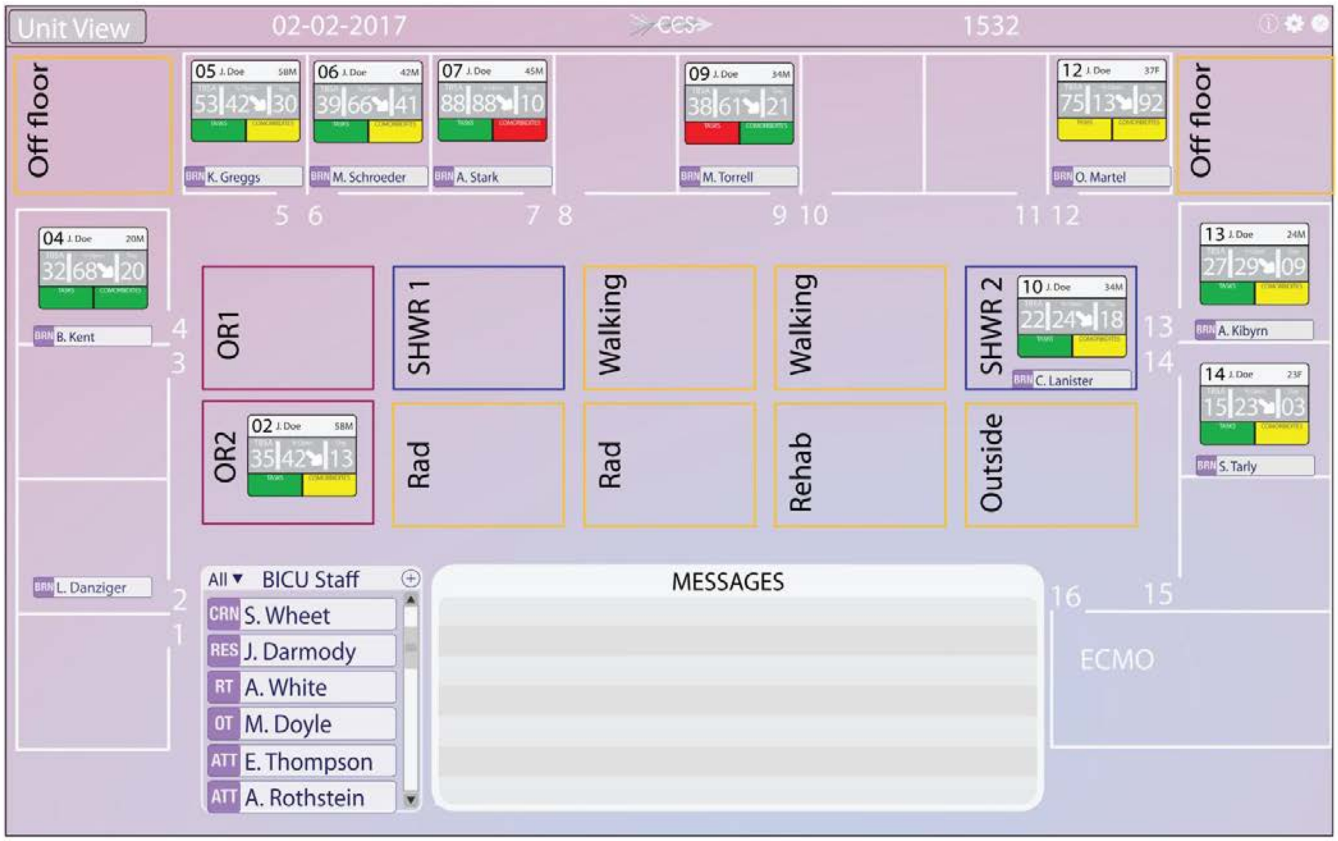
Unit View



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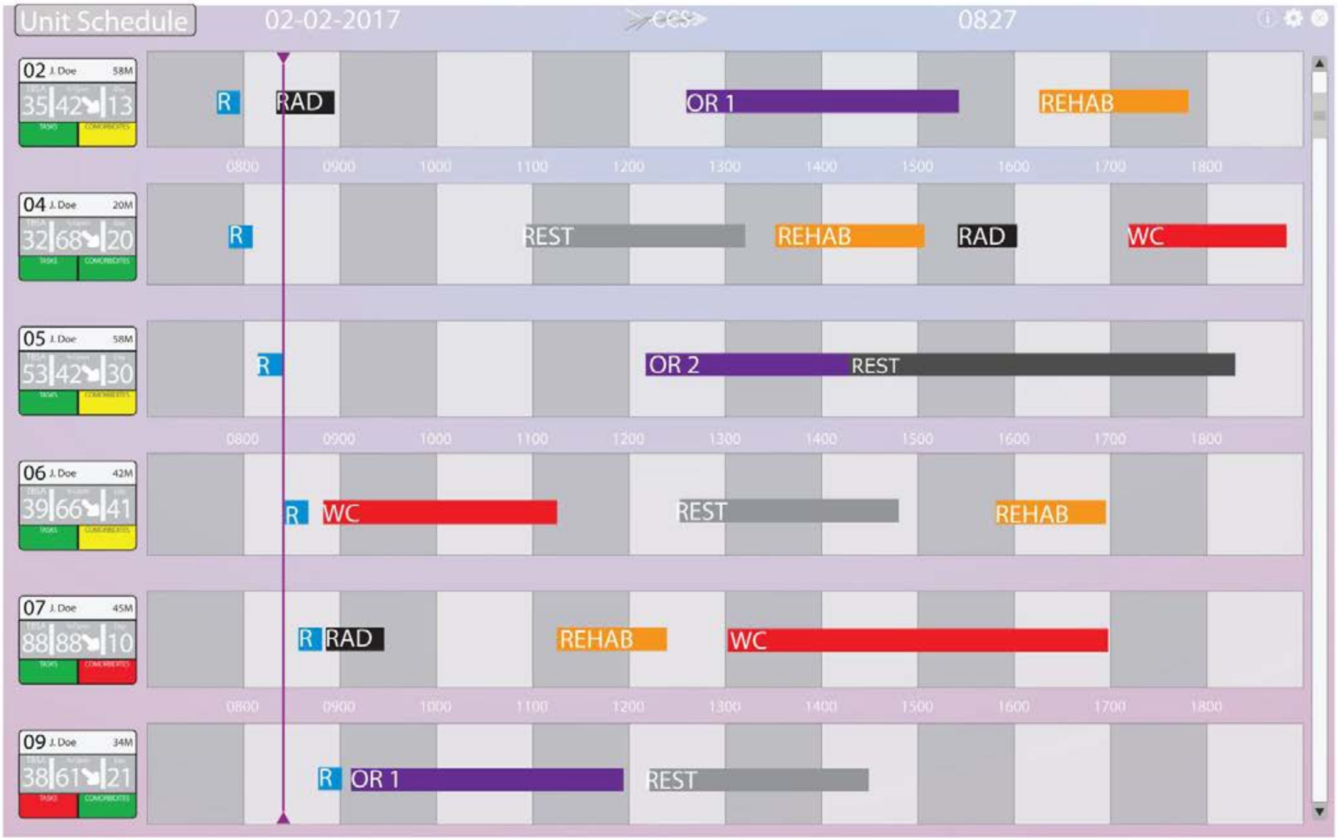
Unit View: Schedule



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Pop Quiz!

Q. What’s the hardest part of this project so far?

Pop Quiz!

Q. What's the hardest part of this project so far?
A. Access to patient data.

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Next Steps

- Develop a prototype compatible with DoD IT requirements
- Test and validate the prototype in concert with other IT solutions that are currently in use
- Field in a clinical setting

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Your comments and correspondence are welcome.

Christopher Nemeth, PhD
cnemeth@ara.com

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